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TRANSACTIONS.

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No. 825.

STANDARD LEVEE SECTIONS.

By H. ST. L. COPPÉE, M. Am. Soc. C. E.

PRESENTED FEBRUARY 2D, 1898.

WITH DISCUSSION.

In engineering works covering an extended field, with operations involving practically the same conditions, system and economy are obtained by the adoption of general standards of form and specification. This is particularly true of the levee work on the Mississippi River, extending over a reach of about 1 000 miles of river, with some 1 200 miles of levees, and where there is but slight variation in climatic, topographical and geological conditions.

For convenience of administration the Mississippi River Commission has divided the portion of the alluvial basin from Cairo to the Gulf into four districts, each of which is placed under the supervision of an officer of the United States Engineer Corps. These districts include the levees built by the local, State and county boards, but which are, to a great extent, maintained by the Government. The first and second districts, extending from Cairo to the mouth of the White River, have been consolidated and are under one officer. The third district reaches from White River to Warren-

ton, just below Vicksburg, and the fourth thence to the head of the passes.

The climate varies but slightly in this entire reach of river, the winter in the upper districts being more severe and extended, but the other seasons partaking of practically the same changes. The high-water conditions are much the same, varying in average height of overflow and time of maximum gauge reading. The topography is similar: A flat alluvial plain intersected by numerous bayous and lakes, old river arms, etc., having slopes gently declining from the river and in the direction of its flow.

The foundations on which the levees stand and the material of which they are constructed are of the same geological epoch, and, generally speaking, were formed by the same agencies throughout. In the lower district the alluvium is more compact and tenacious and resists caving better than in the districts above.

In 1882 the first allotment for levee building was made by the Commission, and the work of construction was undertaken with the same dimensions of cross-section, and the same specifications required by the local boards.

Since 1882 approximately 50 000 000 cu. yds. of earth have been placed in the levees by the Government. The form of these levees has varied with the local conditions, but since 1887 the general specifications have not been radically changed.

A few years ago the Government adopted standard sections which have since been adhered to, except in cases where the conditions demanded more specific treatment. The first, second and third districts have practically the same standard for all levees on ordinarily good foundations, and when constructed of material not below the average in strength.

The standard dimensions are: Crown, 8 ft.; front or river slope, 3 to 1; back slope, 3 to 1. Where the levee is over 11 ft. in height, a banquette, at an elevation of 8 ft. below the top of the main levee, is added. The slope of the crown of this banquette is 10 to 1, width of crown 20 ft. and back slope 4 to 1. Where the foundation is bad, or the material weak, the banquette section and perhaps the front slope of the main levee is increased.

The dotted lines in Fig. 1 show the shrinkage section to which levees are built. The specifications, as shown in the accompanying

FIG. 1.

FIG. 2.

statement (extract from specifications of 1897), require the levee to be constructed in 2-ft. layers with scrapers, on a well-grubbed and thoroughly plowed foundation containing a small exploration muck-ditch filled back with strong material, the best to be found in the vicinity, and sodded at 2-ft. intervals with Bermuda grass.

In the fourth district the dimensions of the standard adopted vary with the height, and are intended to conform more nearly to the supposed theoretically perfect section. These variations may be further modified as in the other districts when required by abnormal condition of foundation, material of construction, wave wash, etc.

For levees from 5 to 10 ft. in height, the crown is 8 ft., the river slope is 3 to 1, and the land slope $2\frac{1}{2}$ to 1.

For levees from 10 to 15 ft. in height the crown is 8 ft., the river slope is 3 to 1, and the land slope 4 to 1 to within 5 ft. of the crown; thence to the crown it is $2\frac{1}{2}$ to 1.

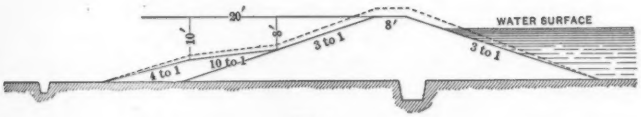


FIG. 1.

For levees from 15 to 20 ft. in height the crown is 8 ft., the river slope is 3 to 1, the first 8 ft. of the land slope from the ground is 6 to 1, the next 6 ft. 4 to 1, and thence to the crown $2\frac{1}{2}$ to 1.

Fig. 2 shows these sections and the method of placing allowances for shrinkage.

In the upper districts 10% of the height, both in wheelbarrow and team work, is required for shrinkage.

These standard sections are expected to withstand the water to within 3 ft. of the crown of the levee, without excessive saturation or change of form, and to give unqualified protection under all normal conditions of foundation and materials of construction.

When subjected to water above the 3-ft. line, though they are intended to remain intact, they cannot be considered, either theoretically or practically, standards of excellence.

Plate XI, Fig. 1, shows a crevasse hole in a levee of standard section. At the time the photograph was taken the crevasse was being

drained; a few days later the construction of the levee was commenced at the end shown, and was carried forward through the hole. Fig. 2, Plate XI, shows a standard levee, 15 ft. high, under construction.

About two years ago it occurred to the author to compare the third district levee section with all the old American sections and with those used in foreign countries, in order to determine what evolution in levee building there had been, if any, and how the practice in one part of the world compared with that in another; each growing out of the necessity for protection against flood, modified by the restrictions of economy, and each beginning with the simple methods taught by good practical sense, untutored in any scientific knowledge of earth or water.

The foreign sections were taken almost exclusively from the valuable paper by William Starling, M. Am. Soc. C. E., entitled "Some Notes on the Holland Dikes,"* and its discussion. Figs. 3, 4, 5 and 6 are cross-sections of old state levees and foreign levees, and show this comparison; the principal dimensions of each levee being indicated thereon; the third district standard being represented by full lines, and the foreign sections by dotted lines. Where the area of the latter is the greater, and is outside of the standard, it is shown with a heavy shading. Where the standard section exceeds the foreign, it is indicated with a light shading. The high water shown is that of the foreign rivers, and in most instances it is less than 3 ft. below the crown of the levee, and is not necessarily the highest water the levee has to withstand at that particular locality. By raising the standard section to the 3-ft. limit the comparison is more favorable to it; but this was not done, as the standard thus far in this country has been frequently required to hold out water to the crown, and will continue to be thus strained until many more millions of the public funds have been expended in raising the general line on the Mississippi to an elevation commensurate with the maximum high water produced by the confinement of the flood between continuous levee lines.

By an examination of the sections and the table of approximate areas and differences it will be seen that as a general rule the old levees in this country from 1717 to 1835 were constructed with a smaller section than the standard. The levee of 1717 at New Orleans

* *Transactions*, Vol. xxvi, p. 559.

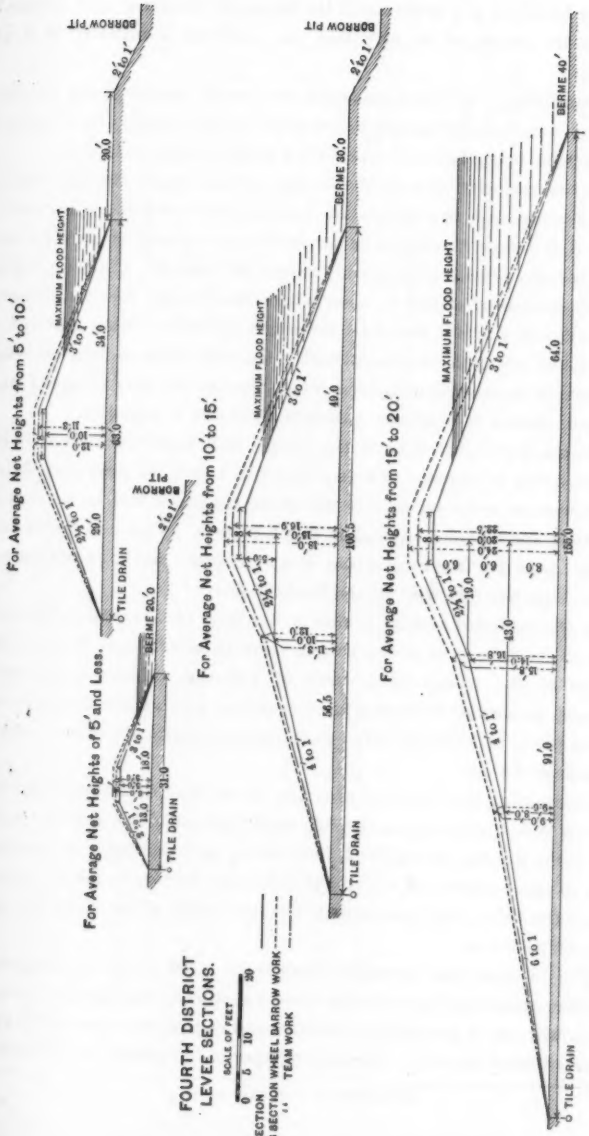

For Average Net Heights from 5′ to 10′.
For Average Net Heights of 5′ and Less.
For Average Net Heights from 10′ to 15′.
For Average Net Heights from 15′ to 20′.
BORROW PIT
MAXIMUM FLOOD HEIGHT
TILE DRAIN
BERME 20.0
BERME 30.0
BERME 40′
FOURTH DISTRICT
LEVEE SECTIONS.
SCALE OF FEET
NET SECTION
CROSS SECTION WHEEL BARROW WORK
" TEAM WORK

FIG. 2.

cannot be taken as a criterion of the levees of that date, as it occupied one of the streets of the city and was used for a roadway 18 ft. in width.

From 1854 to 1873 the standard was nearly similar to the present, but was not generally adopted on account of the necessity for economy; the section being reduced to obtain a greater length of line.

In the majority of cases the foreign levees exceed the standard in cross-section, but, in that portion between the crown and a horizontal plane 8 ft. below, the excess in proportion to the area is much greater than below. This is very plainly shown in Table No. 1 in the columns of percentages of excess to area where the foreign levee is greatest, and is due to the fact that these levees are roadways, either graveled or paved, and are used for general traffic; the wide cross-section not being adopted as a protection against water, but as the only means of land communication in a country constantly subject to overflow.

On the new South dike of the Linge, (left bank) sections 37 to 40, the excess in percentage of area above 8 ft. is not as pronounced, because here an excessive section was given the lower area on account of the weak and treacherous soil on which it rests. This new South dike of the Linge is "the largest and most elaborate work, except the sea dikes, that was met with in the Netherlands." *

In the standard section, which is not used as a roadway, a crown such as given to most of the Dutch, German and Italian levees (from 16½ to 25 ft.) would be a waste of material, adding unnecessary strength to withstand hydrostatic pressure, and weight placed in the wrong place to economically counteract hydraulic action as it occurs in saturated soils.

Eliminating the excess in area due to roadway, it is found that the foreign and American practice are much the same in many instances, and if the greater strength of foundation and materials of construction, in many instances, of the third district levees, be taken into account, the theory and practice on the two sides of the ocean will appear very similar.

The question that naturally arises in the mind of the levee engineer is: How near is the theoretically correct section to this standard, which has grown out of practical experience and compares so favorably with those adopted abroad? This short paper is submitted to the Society

* *Transactions*, Vol. xxvi, p. 613.

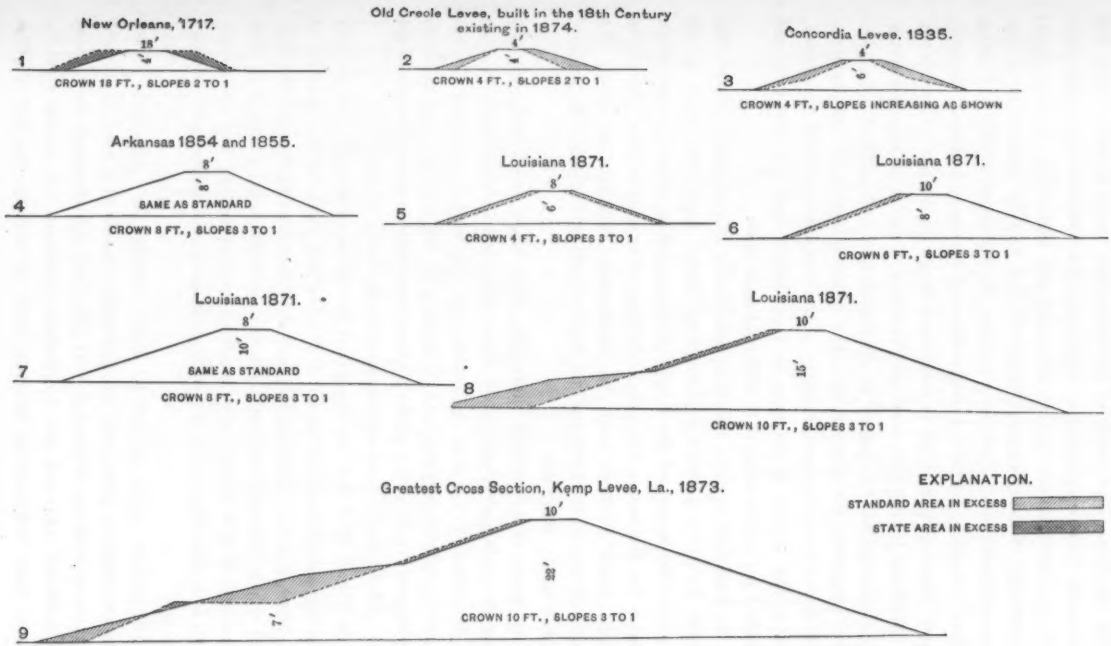

New Orleans, 1717.
18′
1
CROWN 18 FT., SLOPES 2 TO 1
Old Creole Levee, built in the 18th Century existing in 1874.
4′
2
CROWN 4 FT., SLOPES 2 TO 1
Concordia Levee. 1835.
4′
3
CROWN 4 FT., SLOPES INCREASING AS SHOWN
Arkansas 1854 and 1855.
8′
4
SAME AS STANDARD
CROWN 8 FT., SLOPES 3 TO 1
Louisiana 1871.
8′
5
CROWN 4 FT., SLOPES 3 TO 1
Louisiana 1871.
10′
6
CROWN 6 FT., SLOPES 3 TO 1
Louisiana 1871.
8′
10′
7
SAME AS STANDARD
CROWN 8 FT., SLOPES 3 TO 1
Louisiana 1871.
10′
15′
8
CROWN 10 FT., SLOPES 3 TO 1
Greatest Cross Section, Kemp Levee, La., 1873.
10′
27′
7′
9
CROWN 10 FT., SLOPES 3 TO 1
EXPLANATION.
STANDARD AREA IN EXCESS
STATE AREA IN EXCESS

FIG. 3.

with the hope that some of the members, many of whom have had long and varied experience, involving the saturation of soils, clays, etc., in dams, levees, canals, etc., and are learned in the theoretical knowledge of many engineering problems, may be induced by discussion to throw some light on a subject so important in this and also in other countries, where extensive lines of levees and earthen dams are used, consuming in their construction large public and private funds.

Without taking into account the effect of waves on exposed levees, which necessitates recourse to special slopes and methods of protection, planking, revetments, etc., the whole question of standard section depends on the permeability of the embankment and foundation, that is, the extent of seepage, or percolation, and the best form and method for overcoming it in different materials.

In buckshot or clay, which is practically impermeable, the section might be given a strictly theoretical form, dependent alone on the height of the water and the weight of the buckshot; allowing some crown merely for increasing the height in time of excessive flood, the slopes being plane surfaces with an inclination sufficient to insure the required weight to counteract the hydrostatic pressure and the angle of repose of the material.

In cases of permeable materials, light clays, sand and loam, the levee becomes partly saturated when subjected to high water, the line of demarkation between saturated and dry soil descending in a hydraulic gradient varying in inclination with the soil of which the levee is composed, and being probably very irregular in trace because of the lack of homogeneity of the material in the body of the levee.

In Fig. 7, if *A B* is the supposed line of saturation, it will be seen that the material shown above *F D* adds but little to the strength of the levee, and the additional weight only increases the force that would tend to push the dry section down the semi-saturated plane *A B*. The banquette *G E F H* acts as a buttress, counteracting any such tendency, and distributes the weight in the most economical and effective manner.

In surface soils, subject to direct rainfall or percolation from adjacent watered areas, the ground-water stands at a level dependent on the composition of the soil, both physical and chemical, the natural and artificial voids and the hydrostatic pressure. In nearly all soils, remote from intersecting fissures, wells or streams, the line or plane

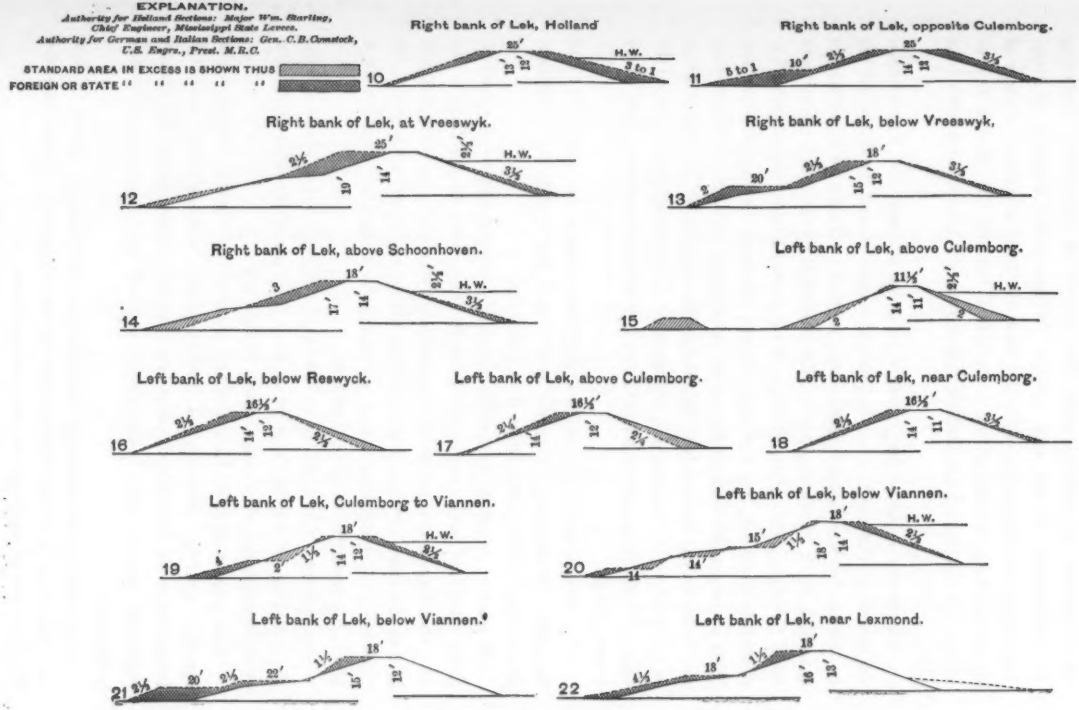

EXPLANATION.
Authority for Holland Sections: Major Wm. Starling, Chief Engineer, Mississippi State Levees.
Authority for German and Italian Sections: Gen. C.B. Comstock, U.S. Engrs., Pres. M.R.C.
STANDARD AREA IN EXCESS IS SHOWN THUS
FOREIGN OR STATE " " " " "
Right bank of Lek, Holland
10
25'
13'
12'
H.W.
3 to 1
Right bank of Lek, opposite Culemborg.
11
5 to 1
10'
2½
25'
14'
12'
3½
Right bank of Lek, at Vreeswyk.
12
2½
25'
2½
H.W.
19'
14'
3½
Right bank of Lek, below Vreeswyk.
13
2
20'
2½
18'
15'
12'
3½
Right bank of Lek, above Schoonhoven.
14
3
18'
3½
H.W.
17'
14'
3½
Left bank of Lek, above Culemborg.
15
11½'
2½'
H.W.
3
14'
11'
3
Left bank of Lek, below Reswyck.
16
2½
16½'
14'
12'
2¼
Left bank of Lek, above Culemborg.
17
2¼'
16½'
11'
12'
2¼
Left bank of Lek, near Culemborg.
18
2½
16½'
14'
11'
3½
Left bank of Lek, Culemborg to Viannen.
19
4
18'
H.W.
2'
1½
14'
12'
2½
Left bank of Lek, below Viannen.
20
18'
H.W.
15'
1½
14
14
13'
14'
2½
Left bank of Lek, below Viannen.
21
2½
20'
2½
22'
1½
18'
15'
12'
Left bank of Lek, near Lexmond.
22
4½
18'
1½
18'
13'
13

FIG. 4.

of saturation is parallel with the surface of the ground, following the inclination of hill and valley. Where wells, fissures, or river-beds occur in the surface soil, the line of moist material, or plane of upper surface of saturation, is inclined toward the fissure, well or river, the degree of inclination depending on the consistency of the soil.*

Where the hydrostatic pressure is great enough, the soil becomes saturated to the surface, as is often the case in the land behind the levees on the Mississippi during an overflow. Where an impermeable material, such as Mississippi Valley buckshot or clay (not an ordinary soil), overlies sand, and the latter is subjected to any considerable hydrostatic pressure, no seepage occurs through the upper stratum. This is frequently demonstrated in excavating levee borrow-pits when the water in the river is near the bank-full stage and the top stratum is a buckshot of considerable thickness. The pit remains dry until the plow or scraper penetrates to the sand, when it becomes in a very short time a pond.

The saturation of the soil is due to two causes, its ability to hold the water by capillary reservoir action, and the hydrostatic pressure. The former differs greatly in different soils.

If a levee, built of permeable material, extended in cross-section a great distance, with crown, say 1 000 ft. wide, instead of 8 ft., the line of saturation would probably be parallel to the crown for some distance and at the same or a greater elevation than the water in the river, depending on the capillary power of the material and the length of time the levee was subjected to pressure.

By reducing the width of crown to the normal levee section, 8 ft., the water of saturation is affected, as in the case of the well or river in surface soils, and its surface made to incline.

The power of soils to resist the pressure of water is due to their specific gravity, fineness of comminution, cohesiveness, and the irregularity of individual particles. Coarse sharp sand has greater resisting power than that composed of fine, smooth, rounded particles.

The author estimates the strength of materials, as found in this levee district, to resist deformation due to seepage, or their value for levee purposes, in about the following order:

* See *Bulletin No. 5*, Weather Bureau, 1892, on Ground-Water.

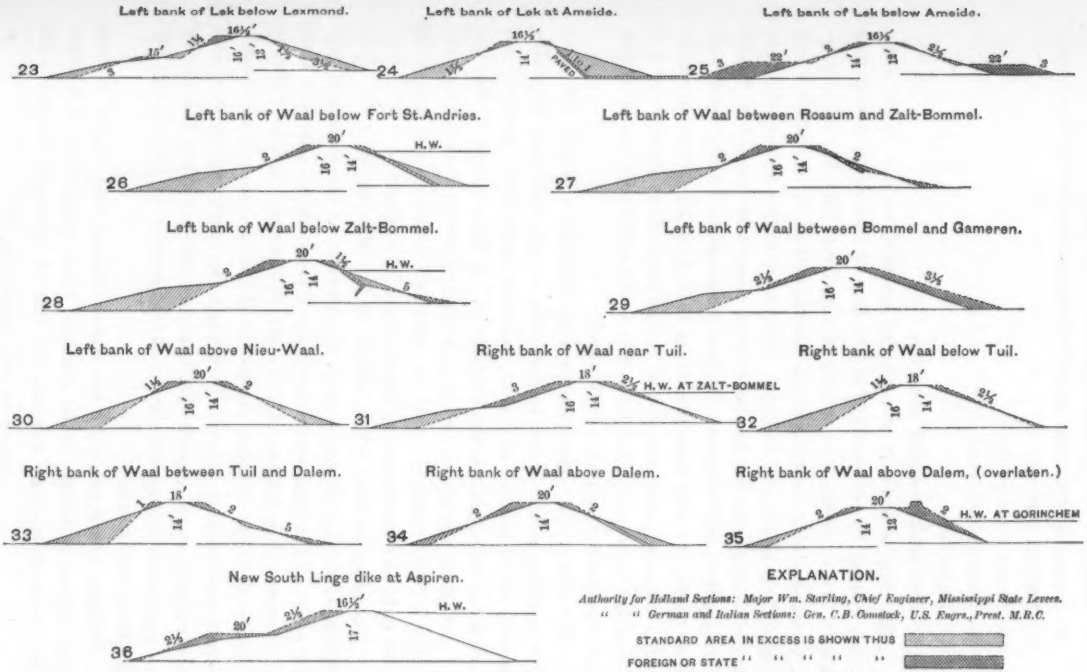

Left bank of Lek below Lexmond.
Left bank of Lek at Ameide.
Left bank of Lek below Ameide.
Left bank of Waal below Fort St. Andries.
Left bank of Waal between Rossum and Zalt-Bommel.
Left bank of Waal below Zalt-Bommel.
Left bank of Waal between Bommel and Gameren.
Left bank of Waal above Nieu-Waal.
Right bank of Waal near Tuil.
Right bank of Waal below Tuil.
Right bank of Waal between Tuil and Dalem.
Right bank of Waal above Dalem.
Right bank of Waal above Dalem, (overlaten.)
New South Linge dike at Aspiren.
H. W.
H. W. AT ZALT-BOMMEL
H. W. AT GORINCHEM
EXPLANATION.
Authority for Holland Sections: Major Wm. Starling, Chief Engineer, Mississippi State Levees.
" " German and Italian Sections: Gen. C. B. Comstock, U.S. Engrs., Prest. M.R.C.
STANDARD AREA IN EXCESS IS SHOWN THUS
FOREIGN OR STATE " " " " "

FIG. 5.

(1) Buckshot and gravel tamped in shallow layers.
(2) Buckshot artificially mixed with sharp sand in shallow layers.
(3) Buckshot or clay.
(4) Heavy strong soils.
(5) Coarse sharp sand.
(6) Light soils.
(7) Fine sand, rounded particles.

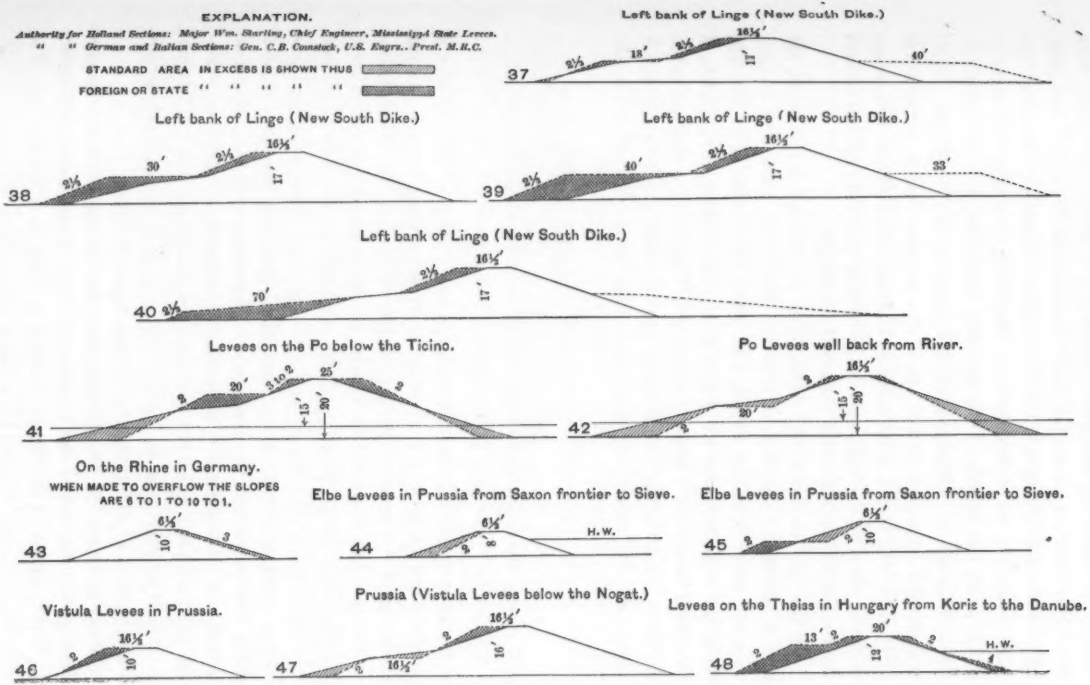
The value or strength of a levee of standard section can be pretty fairly gauged by the position of the line of saturation during flood stages, if it is constructed strictly in accordance with the accompanying specifications, contains no perishable matter, is located on a good foundation, and is well drained. As far as the author's knowledge goes, the position of this line has never been accurately determined for different soils in this country. Surface observations during floods have been made, but with little benefit, as they have never been systematically recorded, and are at best casual inspections made when it is necessary to devote all available time to the administrative rather than the experimental function of the work.

The author has experimented with diminutive levees, but found the capillary action of the lighter soils so extensive that the entire section would become saturated, and after many futile attempts that method of investigation was abandoned. If the position of this line of saturation was known for all soils used in levee building, a theoretically perfect standard could be obtained which would reduce the cost of levee construction to known limits of economy.

The paper entitled "The Levees of the Mississippi River,"* by William Starling, M. Am. Soc. C. E., refers to an extensive and careful series of experiments on earths for levee building purposes, made in Germany from 1872 to 1877, by Mr. B. Schelten, and published in the *Zeitschrift für Bauwesen* for May of the latter year. These experiments were made to determine shrinkage, strength, resistance to still and running water, capacity for retaining water, etc., but how reliable or applicable the results are to levee practice in this country the author is not informed.

Surface observations by the writer, during high water, indicate that in most materials, in the standard levee, with crown 3 ft. above the water, if carefully drained, the line of saturation intersects the

* *Engineering News*, January 30th, 1896.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STANDARD AREA IN EXCESS IS SHOWN THUS
FOREIGN OR STATE " " " " "
Left bank of Linge (New South Dike.)
37
Left bank of Linge (New South Dike.)
38
Left bank of Linge (New South Dike.)
39
Left bank of Linge (New South Dike.)
40
Levees on the Po below the Ticino.
41
Po Levees well back from River.
42
On the Rhine in Germany.
WHEN MADE TO OVERFLOW THE SLOPES ARE 6 TO 1 TO 10 TO 1.
43
Elbe Levees in Prussia from Saxon frontier to Sieve.
44
Elbe Levees in Prussia from Saxon frontier to Sieve.
45
Vistula Levees in Prussia.
46
Prussia (Vistula Levees below the Nogat.)
47
Levees on the Theiss in Hungary from Koris to the Danube.
48
H.W.

FIG. 6.

back slope below the banquette, which is 8 ft. below the crown. With the water near the crown of badly constructed levees of very poor, light materials, the section becomes almost completely saturated; the only resistance to subsidence, or sloughing, holding the levee in place, being the weight of the abutting banquette and unbroken sod. Local drainage of slopes in such instances is very beneficial. Badly constructed buckshot levees often slough after being subjected to pressure a long time; great sections sliding, seemingly on some soapy inclined plane of cleavage, and not becoming generally saturated, as in the case of lighter and more permeable materials.

In the new government levees, built on average foundations, the line of saturation varies from near the banquette to a 4 to 1 slope, with the water near the crown, but when the water is at the 3-ft. limit, the slope becomes 5 to 1 to 8 to 1. The degree of saturation as perceived on the back slope is very quickly reduced by a slight fall in the river, owing to the reduction of pressure and the compacting influence of the water. In many instances, where the levee remains

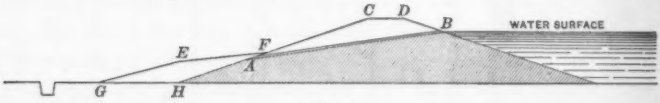


FIG. 7.

under pressure for a long time with the water near the crown, after a certain limit of time the seepage decreases, owing probably to the shrinkage of the material closing the interstices between the particles.

The problem of providing against excessive seepage is one of great importance in levees placed on bad foundations, and sometimes can only be solved by the use of impermeable cores, consisting of muck-ditches sunk to strong strata and filled with tamped clay, or sheet piling driven beyond the limit of the dangerous subsoil. Cores of cement and other materials have been advocated at different times, but never adopted on account of their great cost and the uncertainty as to their effectiveness in banks subject to such excessive shrinkage and expansion at different seasons and stages of water.

Many instances of bad foundations, and levees built of poor material giving way under the pressure of high water, have come under the investigation of the writer; notably in 1892, in Arkansas, that of a levee constructed of sand on a sandy foundation underlaid by logs

and other decayed vegetation. During the flood of that year, the water forced a passage under the levee, through a channel formed in rotten logs, and, when the pressure became sufficient, without warning burst out beyond the back slope. At first the entire foundation was undermined, leaving the upper portion of the levee standing in the form of a bridge which was soon swept away by the violence of the current.

Seepage and percolation are natural in foundations and embankments and are not to be feared when the former is free of logs and holes and the latter is constructed in accordance with the latest practice; but, is the standard the most economical and the best for general practice on the Mississippi River, with the available material and necessary restrictions in methods of construction?

It is the opinion of some engineers that, as long as the results from practical methods are fairly satisfactory, further investigation is but an ultra-refinement and unnecessary; but in the present status of engineering practice, when "the best results at the least cost" seems to be the prevailing motto, such an argument has but little meaning to those looking for the highest standard attainable, even in small matters.

It is by striving for the perfect in all things that the plane of a higher civilization is reached, in which every branch of engineering is a most important factor.

EXTRACT FROM SPECIFICATIONS; THIRD DISTRICT; MISSISSIPPI RIVER COMMISSION.

38. "*Preparation of Ground.*—The center line of the levee will be staked out by an agent of the United States. The fill and slope stakes shall be set by the contractor, from notes furnished him. All logs, trash, and other objectionable matter must be cleared from the ground to be covered by the new embankment, and for a distance of 5 ft. beyond the slope stakes. The entire surface between slope stakes must then be thoroughly broken with a spade or plow, in order to form a bond with the earth deposited, and such top soil as in the opinion of the engineer in charge is unfit for the foundation shall be removed. A muck-ditch shall then be cut, when required by the engineer in charge, of such dimensions as he may direct. The muck-ditch for new work shall be cut 3 ft. from the center line of the levee on the side next the river, great care being taken not to displace any of the stakes of the center line; for enlargement work, the muck-ditch shall

be cut near the base of the old levee. All trees, stumps, large roots, crawfish holes, and buried logs, where they are known to exist, must be dug out for a distance of 5 ft. beyond the slope stakes or base of the levee. After inspection and measurement, these excavations and the muck-ditch must be filled in, with approved material obtained from without the base of the levee, and thoroughly tamped while being filled, to the satisfaction of the engineer in charge, or his designated agent. All of the foregoing work shall be completed for at least 300 ft. in advance of the embankment."

39. "*Embankment.*—The embankment will be started full out to the side stakes, and be carried regularly up to gross fill, in layers not exceeding 2 ft. in thickness, when built by scrapers, and 6 ins. when built by wheelbarrows. In wheelbarrow work, the earth will be carefully tamped either by wheeling over the embankment or by employing one rammer to two wheelbarrows. When the embankment has been brought up to the proper height, it shall be dressed, and planted with living tufts of Bermuda grass, 4 ins. square, and not more than 2 ft. apart, well pressed into the earth and lightly covered with soil, to the satisfaction of the engineer in charge, or his designated agent. The contractor will cut down all trees, both great and small, to a distance of 100 ft. from the base of the levee on both sides."

40. "*Borrow Pits.*—Only clean, unfrozen earth, free from all foreign matter, shall be used in constructing the embankment. It will be procured on the river side, unless otherwise directed in writing by the engineer in charge, and from such places as may be condemned for the purpose by local levee authorities. In excavating and removing it, great care must be taken to injure or disfigure the land as little as possible. In no case must it be obtained within 40 ft. of the base of the levee on the river side, or within 100 ft. on the land side, and the side slope of the pit next to the embankment not to be steeper than 1 on 2. Any encroachments upon the limits of either side will be measured by the engineer in charge, or his designated agent, and deducted from the amount of the final estimate. At such intervals as may be directed by the engineer in charge, or his designated agent, traverses must be left across the borrow-pits to prevent the flow of a current along the levee. The distances between the traverses will not be more than 500 ft. They shall be at least 10 ft. wide on top, with slopes of 1 on 2. Borrow-pits must not exceed 3 ft. in depth on the side next to the levee, but they may gradually deepen with a slope of 1 on 50 when on the river side, and 1 on 100 when on the land side of the levee. All existing levees, or parts of old levee, must be left, unless written permission of the engineer in charge is given for their removal."

TABLE No. 1.—Showing the Total Area in Excess, Corresponding to Comparative Sections on Figs. 3, 4, 5 and 6; the Difference or Amount of Foreign over Standard Area and *vice versa*; the Same for Sections Above and Below a Horizontal Line 8 Ft. Below Crown of Levee; also the Total Areas Above and Below that Line and the Percentage of Excess to Total. All Areas are in Square Feet.

No. of section.	Area in Excess.				Area in Excess Below 8 Ft.				Area in Excess Above 8 ft.				Total area above 8 ft.	Total area below 8 ft.	Percentage of excess to total, above 8 ft.	Percentage of excess to total, below 8 ft.
	Area.		Difference.		Area.		Difference.		Area.		Difference.					
	Foreign.	Standard.	Foreign.	Standard.	Foreign.	Standard.	Foreign.	Standard.	Foreign.	Standard.	Foreign.	Standard.				
1	34	.....	34	.....	.....	.....	.....	.....	34	.....	34	.....	104	.....	33	.....
2	.....	20	.....	20	.....	.....	.....	.....	.....	20	.....	20	.....	.....	.....	.....
3	.....	52	.....	52	.....	.....	.....	.....	.....	52	.....	52	.....	.....	.....	.....
4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	.....	36	.....	36	.....	.....	.....	.....	.....	36	.....	36	.....	.....	.....	.....
6	.....	48	.....	48	.....	.....	.....	.....	.....	48	.....	48	.....	.....	.....	.....
7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	48	82	.....	34	.....	82	.....	82	48	.....	48	.....	272	640	13	+13
9	53	94	.....	41	5	94	.....	89	48	.....	48	.....	272	1 640	18	+ 5
10	205	.....	205	.....	70	.....	70	.....	135	.....	135	.....	302	384	35	18
11	284	.....	284	.....	161	.....	161	.....	123	.....	123	.....	374	514	33	31
12	208	.....	208	.....	75	.....	75	.....	133	.....	133	.....	392	945	34	8
13	155	.....	155	.....	83	.....	83	.....	72	.....	72	.....	336	580	21	14
14	182	.....	182	.....	89	.....	89	.....	93	.....	93	.....	352	760	26	12
15	7	111	.....	104	.....	69	.....	69	7	42	.....	35	265	306	13	+22
16	62	36	26	.....	24	21	3	.....	38	15	23	.....	308	368	7	1
17	40	61	.....	21	4	36	.....	32	36	25	11	.....	300	355	3	+ 9
18	82	.....	82	.....	23	.....	23	.....	59	.....	59	.....	324	339	18	7
19	82	28	54	.....	45	.....	45	.....	37	28	9	.....	299	412	3	10
20	74	62	12	.....	27	32	.....	5	47	30	17	.....	299	851	6	+ 1
21	145	4	141	.....	113	.....	113	.....	32	4	28	.....	296	604	9	19
22	100	4	96	.....	68	4	64	.....	32	.....	32	.....	296	672	11	10
23	64	84	.....	20	46	40	6	.....	18	44	.....	26	296	631	9	1
24	13	212	.....	199	.....	157	.....	157	13	55	.....	42	291	412	14	+38
25	135	7	128	.....	114	.....	114	.....	21	7	14	.....	280	450	5	25
26	35	205	.....	170	.....	197	.....	197	35	8	27	.....	332	635	8	+31
27	54	171	.....	117	21	164	.....	143	33	7	26	.....	332	633	8	+22
28	43	241	.....	198	11	228	.....	117	32	13	19	.....	286	825	7	+14
29	142	116	26	.....	56	116	.....	60	86	.....	86	.....	352	800	24	+ 8
30	24	153	.....	129	.....	139	.....	139	24	14	10	.....	304	564	3	+23
31	77	81	.....	4	5	81	.....	76	72	.....	72	.....	336	678	21	+11
32	28	134	.....	106	6	113	.....	107	22	21	1	.....	328	585	0	+18
33	42	136	.....	94	22	101	.....	79	20	35	.....	15	268	466	6	+17
34	31	69	.....	31	.....	64	.....	64	38	5	33	.....	304	462	11	+14
35	82	28	54	.....	4	26	.....	22	78	2	76	.....	340	364	22	+ 6
36	100	.....	100	.....	58	.....	58	.....	42	.....	42	.....	308	948	14	6
37	66	5	61	.....	24	5	19	.....	42	.....	42	.....	308	1 915	14	2
38	188	.....	188	.....	146	.....	146	.....	42	.....	42	.....	308	1 044	14	14
39	253	.....	253	.....	211	.....	211	.....	42	.....	42	.....	308	1 092	14	19
40	338	7	331	.....	296	7	289	.....	42	.....	42	.....	308	1 089	14	27
41	132	164	.....	32	20	164	.....	144	112	.....	112	.....	348	1 363	32	+11
42	16	254	.....	238	.....	15	.....	15	16	239	.....	223	292	1 502	76	+ 1
43	.....	30	.....	30	.....	6	.....	6	.....	24	.....	24	.....	.....	.....	.....
44	.....	45	.....	45	.....	.....	.....	.....	.....	45	.....	45	.....	.....	.....	.....
45	32	41	.....	9	16	.....	16	.....	16	41	.....	25	252	150	10	11
46	29	6	23	.....	.....	6	.....	6	29	.....	29	.....	292	124	10	+ 5
47	35	49	.....	14	.....	49	.....	49	35	.....	35	.....	292	756	12	+ 6
48	171	58	113	.....	58	58	.....	.....	113	.....	113	.....	375	338	33	.....

Remarks.—In the last column the plus sign denotes that the standard section is in excess.

Fig. 3 shows sections 1 to 9; Fig. 4, sections 10 to 22; Fig. 5, sections 23 to 36, and Fig. 6, sections 37 to 48.

DISCUSSION.

Mr. Wait. JOHN C. WAIT, M. Am. Soc. C. E.—On page 205 the author says: "Seepage and percolation are natural in foundations and embankments, and are not to be feared when the former is free from holes and logs," etc. On the Erie canal the engineers do not feel safe if there is percolation and seepage through the banks. There are, it is true, some places on the canal and under the foundations where percolation and seepage exist, and breaks have resulted. Whether the embankments are constructed in accordance with the latest practice is a matter the speaker would not wish to vouch for. In his experience, and in the canal work with which he has been connected, it is the aim to have no percolation through dams or embankments. The rate of slope at the places referred to was about 3 to 1, or not very far from those represented in the paper. The embankments are of puddled clay and stone, or clay and gravel.

Through the salt fields of Syracuse, a little west of that city, there is a place where the foundation of the tow-path embankment is a very porous marl, so-called, and there has been seepage and percolation through the marl underneath the embankment for many years. The water has been conducted away by ditches. It has been a constant source of fear and annoyance, and two or three breaks have occurred there. An embankment in this condition may stand for five years, yet to the speaker it is always a source of danger.

Mr. Sherrerd. M. R. SHERRERD, M. Am. Soc. C. E.—Referring to the Erie Canal embankment where the percolation occurred, it would be interesting to know whether this first percolation carried roily water with it. In all these constructions where the water percolates clear, if it does not come in large quantities, there is no immediate danger. The speaker once had occasion to look into this question in connection with an earth dam with about 30 ft. of water on the up-stream side. The main dam itself seemed to be perfectly dry; at least, there was no indication of percolation on the down-stream side, but through the sand hills on either side there was a considerable flow of water. The dam was built in 1892, and since that time the flow through the hills has diminished, until in 1897 it was about one-quarter of the original amount. From the beginning, however, the water was always clear. The question as to whether the water comes clear or not should settle the point as to the danger of most work where there is percolation. In the case referred to, the hills along the water-line were long; that is, the water would have to travel a great deal further through the hills to get out than if it had come straight through the bottom of the dam. This dam was on a stream with a small drainage area, about $2\frac{1}{2}$ square miles; and having measured the flow of the stream before the construction of the dam and the leakage afterward, it was found that the leakage

at the beginning of the leak was about one-fourth of the flow of the stream. By throwing in gravel along the banks when the leak first occurred, the leakage was decreased a considerable amount in the first month or so after the dam was filled. Mr. Sherrerd.

ALPHONSE FTELEY, President Am. Soc. C. E.—The subject of this paper is interesting, and covers a ground somewhat unfamiliar to engineers in the East. One of its most interesting features is that it shows that the Government has been endeavoring to establish standard sections, which will make the levees secure with the use of as little material as possible within safe limits of percolation. The practice, especially in this part of the country, as Mr. Wait has stated, has been to endeavor to construct embankments in such a way as to have no leakage or percolation; but in the case of the Mississippi levees, it is a question, either of having no levees at all, or of constructing them as economically as possible, and in such a way that they will stand. The regulation of the percolation so that it will take place without interfering with the stability of the structure is, therefore, important. It has been studied abroad with a great deal of care, and in many Indian dams this principle is followed to such an extent that the engineers build a drain in the very heart of the earth dams—on the down-stream side—in order to collect any water that may go through and conduct it safely out by special channels. Mr. Fteley.

As an illustration of the necessity for providing for proper drainage, the speaker referred to a dam made entirely of a bank of gravel and containing about 50 ft. of water. Nothing whatever had been done to prevent the percolation of water, and probably the only thing that saved the dam was the very fact that the material of which it was made was rather fine on the up-stream portion of the embankment, while the lower part was made of coarser gravel. The flow of water through the dam was so large that, at first sight, the latter seemed to be in a dangerous condition. It was ascertained, however, that it had stood more than forty years, and the evidence collected showed clearly that the amount of percolation, although large, was less than it had been immediately after construction. Under those circumstances, it was quite interesting to find, in the notes of the original builder, the statement that he had erected a structure which would last as long as the pyramids of Egypt. A careful examination of the numerous leaks which appeared at the down-stream toe of the embankment disclosed the fact that they were running entirely clear and free from any solid materials. The conclusion reached was that the dam was not in immediate danger, although in a condition which should not be maintained. It was since reconstructed.

The speaker fully agreed with Mr. Sherrerd as to the importance of ascertaining in such a case whether the percolating water is clear or turbid.

Mr. Duryea. EDWIN DURYEA, Jr., M. Am. Soc. C. E.—The designing of levee sections should not be confused with that of canal and dam embankments, as their respective designs are governed by entirely distinct considerations, both as to the economy absolutely necessary and as to the respective duties which the structures have to perform.

As to the first consideration, that of the strictest economy, it is hardly necessary to speak. It may be well to say, however, that because of the far-reaching effect of back-water due to the flat slope of the river, and because of the river being divided into "levee basins," it is necessary that the levee be continuous from its upper to its lower end, throughout the whole length of the basin, in order to afford any adequate protection to a basin; in consequence of which, appropriations for levee construction must, in general, be made to cover the whole length of the basin rather than the construction of an ideal section over any part of it.

The demands for the protective work, as a whole, are so great, including, besides levees, so many costly special features, such as the protection of caving banks and cutting bends, and the needs are so far in advance of the available appropriations that the greatest fund available for levees may be regarded as the least possible amount for which a probable protection can be secured.

The preceding, while an attempt to show that levees cannot be had except with small sections, is, of course, from an engineering standpoint, no justification of their being so built; but a study of the relative duties performed by levees on the one hand, and by canal and dam embankments on the other, will convince one that, for engineering reasons alone, it is perfectly proper to design the former with much smaller sections, considering the quality of material used, than would be suitable for the latter.

The duty of a canal or dam embankment is to sustain the full head of water for which it is designed, for long periods, usually, in this climate, for about nine months in the year; while levees may be regarded as emergency structures, in actual use for only short periods each year (and some years not at all), and even then, generally, under less heads than those for which they were designed.

As instances of the very short periods during which levees are in actual use, the following tables are given. Tables Nos. 2 and 4 show the dates between which the water surface of the Mississippi River was above the level of the natural river bank, or the periods during which the levees were under any head of water whatever; and Tables Nos. 3 and 5 the time of passage of the crest of the rise, during which the levees were subjected to a great and nearly constant head; also the periods during which the heads were more than 4 ft.

From Table No. 2 it will be seen that levees built to withstand heads of presumably 12 ft., with water 3 ft. below the top, were sub-

TABLE No. 2.—PERIODS FROM 1888 TO 1890, INCLUSIVE, DURING WHICH Mr. Duryea. THE LEVEES AT CAIRO, ILL., WERE SUBJECTED TO ANY HEAD OF WATER.

Year.	Interval.	Time.
1888	From March 27th to April 19th =	23 days.
1889	River not above bank level =	0 "
1890	From Jan. 16th to Jan. 30th =	14 days.
	" Feb. 13th " Feb. 20th =	7 "
	" Feb. 27th " April 15th =	47 "
		— 68 "
	Total in 3 years =	91 "

TABLE No. 3.—PERIODS FROM 1888 TO 1890, INCLUSIVE, DURING WHICH THE CAIRO LEVEES WERE SUBJECTED TO GREAT AND NEARLY CONSTANT HEADS; ALSO THE ACTUAL HEADS.

Year.	Interval.	Time.	Heads.
			Feet.
1888	From March 29th to April 10th =	12 days.	From 4 to 6½
1889	No head against levee.		
1890	From Jan. 19th to Jan. 25th =	6 "	" 4 " 4½
	" Feb. 15th " Feb. 19th =	4 "	" 2 " 3
	" March 1st " March 5th =	4 "	" 4 " 7
	" " 5th " " 11th =	6 "	" 7 " 9½
	" " 11th " " 23d =	12 "	" 9½ " 7
	" " 23d " April 5th =	13 "	" 7 " 9½
	" April 5th " " 10th =	5 "	" 9½ " 7
	" " 10th " " 13th =	3 "	" 7 " 4

Total in 3 years, with heads over 4 ft. = 61 days.
" " " " 7 " = 36 "

TABLE No. 4.—PERIODS FROM 1886 TO 1892, INCLUSIVE, DURING WHICH LEVEES AT MEMPHIS, TENN., WERE SUBJECTED TO ANY HEAD OF WATER.

Year.	Interval.	Time.	
1886	From Feb. 20th to March 2d =	10 days.	
	" April 2d " May 4th =	32 "	
	" May 16th " " 28th =	12 "	
		—	54 days.
1887	" Feb. 5th " March 28th =	51 "	
	" May 1st " May 12th =	11 "	
		—	62 days.
1888	" March 29th " April 26th =		28 "
1889	River not above bank-level		0 "
1890	From Jan. 17th to April 25th =		98 "
1891	" Feb. 10th " " 30th =		79 "
1892	" April 7th " June 21st =		75 "
	Total in 7 years =		396 days.

Mr. Duryea.

TABLE No. 5.—PERIODS FROM 1886 TO 1892, INCLUSIVE, DURING WHICH THE MEMPHIS LEVEES WERE SUBJECTED TO GREAT AND NEARLY CONSTANT HEADS; ALSO THE ACTUAL HEADS.

Year.	Interval.	Time.	Heads.
			Feet. Feet.
1886	From Feb. 23d to Feb. 27th =	4 days.	From 0 to 2
	" April 7th " April 13th =	6 "	" 4 " 6
	" " 13th " May 2d =	19 "	" 6 " 8
	" May 2d " " 3d =	1 "	" 6 " 4
	" " 20th " " 25th =	5 "	" 0 " 4
1887	" Feb. 11th " Feb. 16th =	5 "	" 4 " 6
	" " 16th " March 26th =	38 "	" 6 " 8
	" March 26th " " 27th =	1 "	" 6 " 4
	" May 3d " May 8th =	5 "	" 0 " 3
1888	" April 2d " April 5th =	3 "	" 4 " 6
	" " 5th " " 19th =	14 "	" 6 " 7
	" " 19th " " 22d =	3 "	" 6 " 4
1889	No head against levee.		
1890	From Jan. 20th to Feb. 5th =	16 "	" 0 " 4
	" Feb. 17th " " 23d =	6 "	" 0 " 3
	" March 6th " March 14th =	8 "	" 4 " 6
	" " 14th " April 16th =	33 "	" 6 " 8½
	" April 16th " " 19th =	3 "	" 6 " 4
1891	" March 1st " April 21st =	51 "	" 4 " 6
1892	" April 15th " May 11th =	26 "	" 4 " 8½
	" May 25th " June 21st =	27 "	" 4 " 8½

Total in 7 years, with heads over 4 ft. = 238 days.
" " 7 " " " " 6 ft. = 104 "

jected to any head of water only 91 days in 3 years; and from Table No. 3, for the same 3 years, to heads exceeding 4 ft. during only 61 days, and to heads exceeding 7 ft. during only 36 days; and twice to extreme heads of 9½ ft.

From Table No. 4 it will be seen that levees built to withstand heads of presumably 6 ft., with water 4 ft. below the top, were subjected to any head of water only 396 days in 7 years; and from Table No. 5, for the same 7 years, to heads exceeding 4 ft. during only 238 days, and to heads exceeding 6 ft. during only 104 days; and twice to extreme heads of 8 ft.

Not only can levees be regarded as emergency structures, but as temporary ones as well—or rather as structures which have a fair probability of being abandoned while still in good condition, to be replaced, because of caving banks or threatened cut-offs, by new levees in safer locations. A short time spent in watching the caving banks of the Mississippi and Missouri rivers will disabuse anyone of the idea that levees should be regarded or treated as permanent structures, on which increased expenditure will give any certainty of increased safety and time of service.

Even should a levee not be abandoned because of caving banks, a great increase of section would not necessarily make it proof against the river; for the alluvial foundations are poor, in varying degrees,

and levees may, and probably often do, fail because of water working through the ground under them and "blowing up" on the land side. Mr. Duryea.

During the comparatively short periods of highest water it is usual and necessary to watch the levees constantly with a force prepared to make instant repairs; and this necessity may arise from causes entirely independent of the size of the section, such as unusual variations in the surface-slope of the river, due to high winds or to the piling of water in bends, high waves, etc.

With such a constant supervision even saturated embankments may be prevented from sloughing, and so still be able to perform their only duty—that of holding out the water till the rise passes—when any special weaknesses can usually be repaired at some leisure.

In conclusion, while the funds available for levees make it impossible to have them at all, except with small sections, there are many natural conditions which justify the use of sections relatively small in comparison with canal embankments. Canal embankments, in their normal condition, are under full heads of water—levees under no head. The former must hold the water so that the loss by seepage is a minimum, while in levees, seepage is not considered at all, except as affecting their safety. Canal embankments are watched in only a moderate degree while under stress; levees with vigilant and constant care. The former are permanent structures built on firm foundations and are likely to be in use for many years; the latter are on much more uncertain foundations and are liable to be abandoned after only a short use because of the encroachment of the river.

The first consideration in engineering is, and has always been, a safe and full performance of the duty for which the structure is designed; but the second is certainly the accomplishment of this result at the least cost; and each year the standard of good engineering more strictly requires that there shall be no expenditure beyond that necessary to attain the result sought.

While not in the least meaning to advocate the use of unduly small sections for levees, the speaker wishes to emphasize the fact that the duties to be performed by canal embankments and by levees are widely different, and that their design and construction should be governed by different considerations; and that which would, in the case of a canal embankment, be only a fairly satisfactory section, might, in a levee, in view of their relative duties, be wasteful, and hence, poor engineering.

CORRESPONDENCE.

Mr. Douglas. H. S. DOUGLAS, Esq.—The writer does not think that a standard levee section is practicable, as the factors entering into the problem are too numerous and variable. If all the factors mentioned in the paper were known, there is still one which has not been given that would have to be taken into account. In the sentence (page 192) "The high-water conditions are much the same, varying in average height of overflow and maximum gauge reading," the words "and duration" should be inserted after the word "height."

It must be borne in mind that, as levees are commonly constructed, their safety lies in the fact that they are under strain for comparatively short periods. That they break occasionally is to be expected. That they hold as well as they do is a matter of surprise. There are few levees on the Mississippi River which would hold if the extreme high water lasted for a year. This being the condition, two levees precisely similar in material and foundation, one located in the vicinity of Cairo, and the other in the vicinity of New Orleans, would not require the same section. One would be under strain for, say, forty days, and the other for one hundred and twenty days. This principle once established would lead to still further refinements, because the duration of the strain would vary on different parts of the levee, being least at the top and greatest at the bottom. If the minimum thickness of the levee at the extreme flood line is fixed, then the thickness at the base should bear some relation, say as 5 to 60, or whatever may be the duration of the different heights of the water above the base of the levee, as determined by the record of the nearest reliable gauge.

Generally the present standard levee has a crown width of 8 ft., and side slopes of 3 to 1. In a levee of this section, 11 ft. high, assume that the water is against it to a height 1 ft. below the top or grade. At the surface the hydrostatic pressure is zero, and the duration of the strain the minimum. The thickness of the embankment or distance on a horizontal line between wind and water at this elevation is 14 ft. Two feet below grade there is a pressure of, say, 62.5 lbs., and the duration of the strain has increased. The thickness of the embankment has increased to 20 ft. Three feet below grade there is a pressure of 125 lbs. and a further increase in the duration of the strain, but the thickness of the embankment is only 26 ft. At 11 ft. below grade the pressure becomes 625 lbs., the duration of the strain has vastly increased, but the thickness of the embankment is only 74 ft. The pressure has increased ten times, but the thickness of the embankment has not increased in proportion. The fourth district levee sections, as given, are developed somewhat on the lines thus indicated, but they do not go far enough.

In practice, an intelligent levee engineer, who is personally familiar with any designated levee district, and has a minute personal knowledge of the ground to be traversed, will design the best and most economical section for that particular levee. If he has had an extended experience during floods, the principal factor in determining the size of the levee section will be the amount of money available to pay for it. With this as a governing factor, it is scarcely probable that he will have an opportunity to err in the way of an excessive section. Mr. Douglas.

STEVENSON ARCHER, Jr., Esq.—The present construction of levees along the Mississippi River, based upon a theoretical standard of perfection under given conditions in reference to stage of water and uniform material, is set forth clearly in this paper. If in the construction of levees there could be dependence upon a uniform material with known pressure, or regular stage of water, it would be useless to enter into a discussion or to offer any suggestions. However, as these conditions do not exist, a few remarks based upon observation and experience will probably suggest the impracticability of seeking to establish on a theoretical basis a line of levees through the Mississippi River bottom. Mr. Archer, Jr.

First to be considered are foundations. Throughout the Mississippi delta there exist no uniform strata, although the line of demarcation is clear in every instance, there being three distinct classes of soil, namely, buckshot, loam and sand, deposited in different localities and in different order. Instances have been known to the writer where levees built of "buckshot or clay, which is practically impermeable," and in accordance with the specifications in every particular, but with a substratum or foundation of quicksand, have, without water pressure, given way on account of their own weight. Since it is impossible to obtain a uniform material, any theory evolved for soil of any particular character would be out of the question in most instances. In fact, there are long lines of levees constructed of two and sometimes three different kinds of soil, consequently increasing or decreasing the standard of resistance, which must not be a variable quantity in theoretically standard cross-sections.

Admitting the practicability of securing a faultless foundation, there arises the question of seepage, which is considered to be the most disastrous. It is generally believed, after the experience of the high water of 1897, that when the levees are completed to the present established grade, 3 ft. above said high water, that as far as volume and height are concerned they will be sufficient to withstand any future flood not greatly exceeding that of 1897, provided excessive seepage and saturation can be prevented. The evil effects of seepage have been very thoroughly explained, both in the exhaustive description of the Holland dikes,* and in the paper under discussion. The

* "*Some Notes on the Holland Dikes*," by William Starling, M. Am. Soc. C. E., *Transactions*, Vol. xxvi, 559.

Mr. Archer, Jr. most disastrous of these is the sloughing away of the back slope, which leaves without support that portion of the levee immediately under the crown, and this, being thoroughly saturated, follows, and a crevasse is the result.

The banquette was adopted a few years ago as a reinforcement for large levees, to prevent sloughing. Fig. 7 would indicate that the saturation occasioned by seepage stopped at the line of the back slope, a little below its intersection with the crown of the banquette. If this were always the case, the value of a banquette would be established beyond question, but in many instances seepage shows itself at some distance above the banquette, and, draining down aids the saturation which becomes so thorough as to cause sloughing.

Heavy seepage has also been known to occur at an elevation 6 ft. below the top of the slope for a distance of several hundred feet, while the adjoining levee for an equal distance showed few signs of percolation.

The cause of this was doubtless due to the use of material of inferior quality. To avoid the disastrous effects of excessive seepage the writer is of the opinion that wherever new levees are constructed, the inspector in charge should be required to keep accurate notes of the various soils used, the order in which they are placed and the depth of the layers; then, as the river begins to rise up the slopes of the levee, the inspector should be required to observe and record the points where percolation occurs on the slope, and the distance below the water surface. From this information the average hydraulic gradients might be obtained, and slopes parallel to the line of saturation established, thus controlling seepage and forcing it to drain out into the seep ditch near the toe of the slope.

The value of a seep ditch has been regarded apparently with indifference, but in the opinion of the writer it should be included with the specifications, and receive the careful consideration of the engineer in charge. The inclination of the water-shed in the delta is naturally toward the inland streams, and consequently the seep water would eventually find its way through them into the river below.

Although the writer suggests the impracticability of constructing a strictly theoretical levee, he is of the opinion that the best results can be obtained by constant observation and a thorough knowledge of the locality and the material, in connection with a study of methods of construction and actual experience.

Mr. Gordon. B. B. GORDON, Esq.—The question propounded by the author, "Is the standard the most economical and the best for general practice on the Mississippi River, with the available material and necessary restrictions in methods of construction?" is one of great interest and importance to the levee engineer. In levee building, as much as in other engineering works, the question of economy is not to be determined by first cost, as one crevasse may result in enormous loss,

out of all proportion to the relative cost of a levee with large or small section. Mr. Gordon.

As shown clearly by the author, the strength of a levee is largely dependent on the character of the material of which it is built, and, as is well known to those familiar with the work on the Mississippi River, the material may change in the space of a few hundred feet. The two classes of material on which the author places the highest value for levee construction, viz., buckshot mixed with gravel, and buckshot mixed with sharp sand, are rarely ever obtainable in practice within the limits of economy. With buckshot, as ordinarily found, it would appear from experience that the present third district standard, with slopes 3 to 1 on each side, and an 8-ft. crown, reinforced with a banquette, where over 11 ft. in height, is amply strong, and about as economical as can well be obtained. With lighter materials a flatter back slope would be preferable, and at points where exposed to wave wash a very much flatter front slope, even 8 to 1 from the high-water line to a depth of some 4 or 5 ft., with the standard 3 to 1 above and below, is very desirable; and, while much more expensive in construction, is the most economical in the end, in the saving of high-water expense and in subsequent repairs.

The writer had a case in point at Ben Lomond, in the Lower Yazoo district, where, during the high water of 1892, the cost for protection against wave wash was some $1 500 for about 1 mile of very exposed levee. The repair work during the next season was placed on the back slope, and the front slope left as it had been made by the action of the waves, about 8 to 1, for a depth of some 4 ft. below high-water line, and 3 to 1 above. During the flood of 1893 the high-water cost was about $150 on the same levee, and in 1897, the next high-water season, not one dollar was expended on it.

The question of the "line of saturation" referred to by the author, is, as he says, so dependent on the character of the material and method of construction, as well as on the age of the levee, and its previous subjection to pressure, that it is virtually impossible to reach any definite conclusion from it, as to a standard section. In very light soils, and in levees of new construction, almost the entire mass becomes saturated, and sloughing is very liable to occur, while the same levee, after two or three years, will become as firm and compact as buckshot, and be equally safe.

However, as any levee is liable to be subjected to pressure within a few months after its construction, it would be wise to adopt such a section as would make it safe under any circumstances. This section is entirely a matter of judgment and experience, and is dependent on the location, as well as on the material.

In general it would seem to be best to determine the section by the local conditions of soil and location, and not attempt to establish any rigid standard to be adhered to in all cases.

Mr. Fortier. SAMUEL FORTIER, Esq.—From the writer's experience in building earth embankments to retain water, he can approve of many of the statements contained in this interesting paper. There are, however, other features of the work described which he cannot fully comprehend, owing, doubtless, to his ignorance of the character of the materials used and the requirements of the levee sections.

Referring to Fig. 7 the author states that the additional weight of the unsaturated portion of the prism would tend to push it down the semi-saturated plane *A B*. In all ordinary materials, it would be perhaps more correct to state that the weight of the dry prism *F C D B* would tend to make the excessively saturated portion beneath bulge out along the slope *A H*, and occasionally along the water slope. In either case, the dry portion on top is a source of weakness rather than of strength, whenever the material beneath has absorbed so much water as to destroy its cohesiveness and power of resistance. The truth of the above statement was amply demonstrated on the West Branch of the Bear River Canal System in Utah. A portion of this canal was excavated along a steep hill-side, composed chiefly of indurated clay, carrying a high percentage of very fine sand. The canal had a bottom width of about 15 ft., a depth of 10 ft., and a carrying capacity of 1 000 second-feet. The center line was located in such a manner as to keep the water area wholly in excavation, and the excess of material, of which there was an abundance, was dumped on the low side as shown in Fig. 8. During the first three months of operation the bottom and sides of the newly excavated channel absorbed much water, which, collecting beneath the lower embankment, reduced the material to a semi-liquid state and the heavy load above forced the saturated mass outward and caused the slide indicated by the heavy line. A small well-compacted embankment carried up 2 or 3 ft. above the plane of the water surface, with a top width of 6 ft. and side slopes of 2 to 1, would have proved much stronger and safer and could have been constructed for perhaps one-third the cost.

"The whole question of standard section," says the author, "depends on the permeability of the embankment and foundation." From this it may be inferred that if the embankment and foundation were made impervious, a much smaller section would suffice. If, then, the prevention of seepage is so essential a feature in the construction of levee sections, why is an effort not made to render the embankment more compact? If clay is the only material available, the section given by the author is probably the best that can be used. To moisten clay with a view of puddling it increases its bulk and renders it less compact than when it is rolled, or rammed, in a dry state. If, however, a mixture of gravel, sand, loam and clay can be readily and cheaply obtained, the writer suggests that the form of cross-section and the manner of building be slightly modified.

Mr. Fortier.

In scores of instances throughout the Western States it has been shown that the materials of which ordinary soils and subsoils are composed, providing the percentage of clay be small, can be made more compact and impervious to water by simply throwing the materials into water than by any amount of ramming in a dry state. The backfilling of trenches for water pipe, gas pipe and sewers during the past five years in the West has been usually done by filling the trench, after the danger of flotation is prevented, about two-thirds full of water and then scraping or shoveling the backfilling into the water. Subsidence rarely takes place in trenches so filled. In regard to the Mississippi levees, if it were practicable to raise sufficient water from the river to maintain a canal in the center of each levee during its construction, a more compact and impervious embankment could be formed. The water would first be pumped into the muck ditch, which, by being gradually filled in and widened, could be readily converted into a canal and maintained until high-water mark was reached. In this manner, and with the materials named, the writer has built embankments from 20 to 27 ft. in height which were impervious and did not shrink more than 1 per cent. Assuming that the materials near the center of the section could be compacted in the manner described, a smaller section might be adopted. The banquette might be dispensed with and the outer slope changed from 3 to 1 to a slope of 2 to 1.

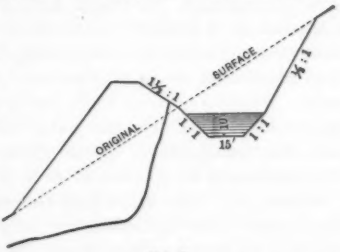


FIG. 8.

In a too hasty perusal of the paper, the writer is somewhat puzzled to account for the allowance of 10% for shrinkage. An embankment which is liable to settle 10% at the center may do very well to support a locomotive and train, but is certainly unsafe to retain water. Of course, as the author remarks, the question of cost must be considered; but, as no hydraulic engineer would attempt to construct reservoir embankments of such loose material, one may be pardoned in asking why so porous a mass of earth is to be preferred on levee embankments.

Mr. Starling.

WILLIAM STARLING, M. Am. Soc. C. E.—The proportions of the cross-section to be given to a water-turning embankment will depend mainly on three circumstances: the foundation, the material, and the manner of construction. In the case of levees, the last element may be said to be a constant quantity. All levees are now built according to certain well-established rules, which are laid down by the author in his extracts from the specifications at present in vogue in the third United States district, which are substantially the same as those used

Mr. Starling. by the State services, at least in Mississippi. It is perhaps not generally understood that many of the local levee boards have done as much for the protection of their own territory as the United States authorities, and some have done much more. The first contribution made by the General Government to the building of levees was in 1882. Since that time, according to the author, they have put up 50 000 000 cu. yds. of earth. Now, the two Mississippi levee districts, since that date, have put up about 25 000 000 cu. yds. by their own exertions, and are still unremittingly engaged in the prosecution of the work. These two districts constitute less than one-fourth of the whole line. All the other districts have contributed more or less, and some of them have been very active. Since the date mentioned, July, 1882, the Lower Yazoo (Mississippi) Levee Board have expended $5 224 235.11, while the United States authorities have spent or are spending about $2 100 000.

The mode of construction being the same in all cases, the variables of the problem are the foundation and the material of which the bank is to be composed. It might not, at first sight, be evident how the nature of the foundation could affect the cross-section of a levee to be built on it. Levees are very cheap constructions, and it is economically impossible to carry them down to solid or impermeable foundations. They have to be built on the surface of the ground; and this may be clay, sand or loam, never solid, always more or less porous and often treacherous. If the ground be of the latter nature, it is often necessary to give the levee a very broad base, to keep it from "blowing up," that is, to keep the water from breaking through under the bottom of the embankment. It is for this reason that so wide a base was given to the New South Linge Dike, in Holland, of which the author has given some sections in Fig. 6.

There are three well-defined classes of earth to be found in the alluvial plain of the Mississippi, namely, clay, sand, and loam. It is observed that the author has included "buckshot mixed with gravel" as one of the possible combinations of material; but, as a matter of fact, there is no gravel available for purposes of levee construction. There are gravel bars in the river, and there are gravel strata underlying the alluvium, belonging to the modified drift formation, 40 or 50 ft. or more beneath the surface of the ground; but there is none which is of any possible use for levees.

The clay is usually decidedly silicious in composition. The sand is mostly fine, and mixed with a considerable proportion of earthy particles. Coarse sand is rare, and pure sand is seldom or never encountered, though sand approximating purity is sometimes found in the vicinity of crevasses, where it has been deposited by the overflowing swift currents of water. In such cases, if the ground is required for a levee, the sand is usually either removed altogether, or placed

in a banquette. It may be said, then, that pure sand is eliminated from the list of levee materials. Where it is absolutely necessary to use it (as it sometimes is), extraordinary dimensions are given to the levee. In one instance, where the levee was a very large and important one, side slopes of one on five were used, and even these dimensions were subsequently increased. The material was sand, as nearly pure as it is found. Loam is a fine silicious earth with a considerable proportion of lime. It resembles in appearance and in composition the Loess of the Missouri valley, and was probably derived from it. Mr. Starling.

As the material for the construction of the levee is usually obtained directly in front of the line, the foundation and the embankment are, in most cases, composed of the same quality of earth. This quality itself, however, is extremely variable. Frequently there is a stratum of the blue or black clay, locally known as "buckshot earth," 1 or 2 ft. thick, on the surface, while under it there is a stratum of sand of indefinite thickness. One hundred or two hundred feet further down the line, the clay stratum may thicken to the extent of 5 or 6 ft., or it may run out to nothing.

In the very rare case of a levee composed of good "buckshot" of tolerably uniform quality, with a foundation of the same extending several feet below the surface, it would, no doubt, be possible to build a safe embankment with less than the ordinary cross-section. Examples of this construction may be seen in the dikes of the Waal, in Holland, of which the author gives sections in Fig. 5 of his paper. The earth along the banks of the Waal is of excellent quality, and uniform to a depth of several feet. In the Mississippi Valley the clay is seldom of sufficient thickness or extent to make any departure from the ordinary proportions advisable, in the direction of a diminished section. On the other hand, it is often thought expedient to increase the standard dimensions in the case of unusually light or treacherous material; but it would be a very difficult task, in the present state of our knowledge, to prescribe any rule for the modifications required, except such as are furnished by the judgment of the engineer. Sand differs from sand, and loam from loam, nor is there any recognized means of defining the gradations of difference. In many cases, experience with particular localities gives valuable hints for future constructions in those places.

HORACE M. MARSHALL, M. Am. Soc. C. E.—While diking is the only method of keeping floods from overflowing the land, and while levee building is a natural and rational outgrowth of conditions which obtain, yet it is highly questionable if it is well to force the growth faster than the river can accommodate itself to the change. It may be that the longitudinal section of the levee more urgently needs looking after than the cross-section, and that natural conditions were better left to work out their own salvation; leave it a fight for the land Mr. Marshall.

Mr. Marshall. against the water, on a basis of "present worth" of the land operating to control the extension of the system.

A filament of water penetrating a levee is impelled by hydrostatic pressure horizontally, and by gravity and capillary action vertically in opposite directions. Capillary action has effect, however, only through a limited distance, determined by the surface tension of the water, the character of the material, and the diameter of the interstices. When the weight of the column of water balances the force resulting from the foregoing causes, capillary action stops; so that the effect is to produce a band of earth and water superposed on the line of saturation; that is, the line where more water added will cause flow. Below this line gravity is not counteracted by capillarity, and friction alone opposes motion. Friction may arise or alter from various causes, which will determine the amount, but the effect will vary only in degree to diminish the velocity of the filament moving under hydrostatic pressure and gravity. Gravity, by drawing the filament downward to a lower plane, subjects its particles to an increased head. Hence the movement will be due to the constant force of gravity and the constantly increasing hydrostatic pressure, and the path will be a parabola. But why not some other curve? A body moving under a constant force and a continually increasing force will travel along a curve of the second degree, and it is not violent to conclude that it will be similar to the path of a body moving under a constant force and a constantly diminishing force, only curved the opposite way. In popular parlance it "will seek the line of least resistance." It is easy to the mathematician to write the equation and demonstrate the line of the resultant of forces acting; along this it will go since there is no consciousness or volition.

If the line of saturation were straight, a rise of the plane of the water on one side of a levee would cause an equal vertical raise of the trace of seepage on the other side, for the material being homogeneous, it would move parallel to itself, but it does not; fact thereby proving the truth of the reasoning. Other conditions being the same, a rise in the water-surface may materially increase the quantity of flow without any great change in the elevation of the trace. The *latus rectum* is changed by the greater difference in velocity in upper and lower strata due to increased difference in head.

Then make the sides of the levee parabolic? Yes, probably, but how shall the parabola be determined in each case? By the resistance offered by the material; that is, the friction opposed to the motion of the water going through. This can, of course, only be ascertained by measurement; probably through pipes driven in the levee, in series, to different depths and at different distances from the front slope, which will permit a determination of the hydraulic gradient under various conditions of the river surface. It will be well to note that the

friction will vary in the same material with the distance its particles are apart, and that distance will be affected in any plane by the weight above the plane. Hence, the weight of the material above the line *A B* in Fig. 7 may be of great value in adding to the friction below, even if it does dispose of the material to better purpose, in preventing overtopping, to take earth from the back slope and heap it up in a wall along the front of the crown. Mr. Marshall.

In this light, the decreased seepage, after the falling of rain upon the levee, or a slight fall in the water, can be accounted for by the added superposed weight; and even the rise of water in the borrow pits, when the surface of the pit is stripped, by the decreased superposed weight; for certainly capillary action must cease at the surface and the water simply stand unless carried off by evaporation.

These considerations would lead to making the landward slope of a standard levee conform to a parabola parallel to the line of saturation and at a distance above it, depending on the efficiency of weight in lessening friction. No greater crown width would be required than is needed to allow for degradation by wear and tear. The river-side slope is governed by consideration of wave wash almost entirely, for, while the material forming the slope offers some frictional resistance to seepage, it could be more advantageously placed back of a vertical plane through the front edge of the crown.

It will be observed that among those who have attended longest in the painful and trying school where experience serves as a teacher, both in foreign lands and on the lower Mississippi, the trend is toward the theoretical section, thus proving once more that science is "but the orderly and methodical digestion and arrangement of the knowledge of the many."

J. D. Van Meter, Esq.—In the writer's connection with the Mississippi levees, it was his lot to hold a position peculiarly favorable for observation during the high water of 1897. Mr. Van Meter.

At the upper end of the division assigned to his charge, which was also the beginning of the Third Mississippi River district, the levee was considered a fairly good one. This was owing to its material rather than its cross-section, as it was not of standard proportions, having slopes of about 2 to 1 on the back, 3 to 1 on the front, an 8-ft. crown, and no banquette. Though the levee was of a good stiff buckshot (which is generally conceded to be the best material obtainable in the Lower Mississippi River bottoms), it was clearly demonstrated that the cross-section was insufficient. There was no crevasse in the levee, but it was only maintained by dint of hard work and the abundance of labor at hand. This portion of the line was built up to a grade 3 ft. above any previous high water, but during previous high-water stages there had been no levee on the opposite bank. The effect was that the flood line along this section of the river was raised

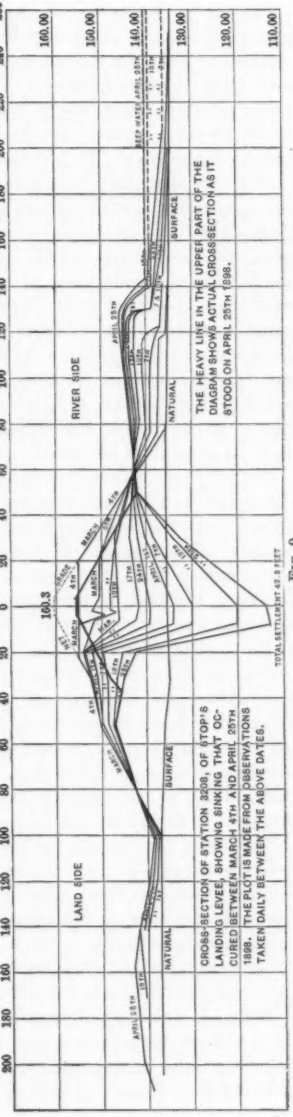
Mr. Van Meter. about 2 ft. The levee was only about 12 ft. high. As the water approached a stage approximately 3 ft. below grade, seepage appeared at the base, and extended up the slope several feet. After the water passed the 3-ft. stage and approached the top of the levee, the whole of the back slope became saturated, and after reaching a stage above the grade of the levee, then confined by a narrow topping, the back slope was a streaming surface of water. The river at that time was rising from 0.3 to 0.4 ft. in twenty-four hours, and the danger was most manifest. The back slope would break at or near the crown, and slide out in a mass, leaving a perpendicular wall of thoroughly saturated earth, which had to be depended on until it could be strengthened. This occurred in a levee of excellent material, though of less cross-section than the standard. The foundation along the line is excellent.

Another feature of peculiar interest was observed at places where the cross-section was of standard dimensions, but the foundation was treacherous. The levee is of sandy loam and maintained a dry back-slope throughout the flood stage, but the base was honeycombed by small cavities that spurted sand to an extent sufficient to fill a depression measuring several hundred cubic yards. The natural result was the caving or settling of the back-slope to compensate for the lost material. These sand-boils are very alarming in appearance, yet they very seldom result disastrously to the levee.

The following notes relate to a faulty, not to say a treacherous, foundation for a levee now being constructed to close one of the crevasses of last season. This levee is of standard cross-section, and 25 ft. high, which is rather exceptional, as the height of levees here would average scarcely more than 14 ft. The construction was commenced and prosecuted under peculiar disadvantages. Excessive rainfall during December and January retarded the progress of the work to such an extent that only the front half of the levee could be built of approved material (buckshot) up to about half of the height, when the engineers were confronted with a rising river that cut off the supply of material from the front. This forced a resort to a silty deposit on the back to complete the embankment to the height to which the front half had been constructed. Slight trouble was experienced from the sinking or settling of the foundation, until the whole cross-section had been brought up to within 5 ft. of the grade. Then there was a breaking and settling just back of the center line of the cross-section. The appearance of this seam or crack was the first intimation of an insecure foundation (other than a slight compression of the entire foundation). The natural surface outside of the base began to bulge or rise on the front, extending 50 or 60 ft. beyond the limit of the slope. This was not a general movement of the base, as it extended only to the front, the line of demarcation being a crack with almost perpendicular walls. The break at first extended over

200 ft., and as the embankment approached completion, on either side of the break, it increased in extent and covered 600 ft. of the incompleted levee, involving a uniform proportion of the section throughout. Fig. 9 illustrates the sinking of this levee. The sections plotted for the different days show the position of the different layers of material under the supposition that they were forced uniformly down into the quick-sand foundation. As material was added to the moving mass, the sinking continued, and it was determined that the movement was lateral rather than due to compression of the base, because the bulging still went on, and the embankment slid on a stratum of stiff buckshot slightly more than 2 ft. below the natural surface of the depression crossed by this portion of the line. This bulging or displacement of material has at its extreme attained a height of 6 ft. above its normal plane. In its movement stumps and trees were carried to a distance of 60 ft. beyond the toe of the slope. Counter pressure would have been resorted to, except that a diminution in the movement was noticeable after the first few days; the break, and consequent movement, being very sudden and decided for the first four days, with a pronounced decrease, even under a continual deposit of material on the moving mass.

This is offered to demonstrate to some extent the impracticability of evolving a section suited to all conditions affecting levee construction, through an alluvial bed of such varied deposits.


160.00
150.00
140.00
130.00
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110.00
RIVER SIDE
LAND SIDE
NATURAL SURFACE
THE HEAVY LINE IN THE UPPER PART OF THE DIAGRAM SHOWS ACTUAL CROSS-SECTION AS IT STOOD ON APRIL 25TH 1898.
CROSS-SECTION OF STATION 3208, OF STOP 18 LANDING LEVEE, SHOWING SINKING THAT OCCURED BETWEEN MARCH 4TH AND APRIL 25TH 1898. THE PLOT IS MADE FROM OBSERVATIONS TAKEN DAILY BETWEEN THE ABOVE DATES.
TOTAL SETTLEMENT 6.0 FEET

FIG. 9.

Mr. Ricketts. PALMER C. RICKETTS, M. Am. Soc. C. E.—This paper is particularly interesting to the writer for the reason that he has just finished a system of dikes for the protection of the City of Corning, N. Y., from floods in the Chemung River. This is believed to be the first complete system constructed in the Northern States, though other cities which greatly need such protection have been prevented from obtaining it on account of the cost. In fact the problem of protection from floods in more or less mountainous districts is different from that to be considered in sparsely settled regions similar to those in which most of the Mississippi River levees have been built. The cost of the land and of the existing structures which must be removed, not only to obtain a base for the embankments, but often to give sufficient water-way between them, together with the cost of the necessary devices for the drainage of the protected areas will generally form the larger part of the expense of the system. As the streams have a much greater slope than the Mississippi, in fact are more or less "flashy," the flood period is short and the dangers resulting from saturation are not so great as in the case of the Mississippi levees. The erosive action of the flood is most to be feared.

In the Corning dikes the river slopes are generally 1 on 3, and the land slopes 1 on 2, with a crown 8 ft. in width. All vegetable material was removed from the base. Grass, for instance, was removed by scrapers, the sod taken off being from 6 to 8 ins. thick. The sod was also removed from the borrow pits, as no vegetable material was allowed in the body of the dikes. This sod was utilized, however, as the slopes and crown were covered with a 6-in. layer of earth suitable for the growth of grass. The layer had to be incorporated with the body of the dike as the building proceeded, and not merely placed on top. After the removal of all vegetable material, the base was ploughed in furrows parallel to the length. Whenever new material had to be placed on an embankment which had been sun-dried or otherwise hardened, as, for instance, when two sections, made at different times, were to be joined, the hardened surface was thoroughly ploughed to insure an intimate mixture and close joint.

The dikes were made in layers, generally with drag- and wheel-scrapers, though for a considerable length, where a long haul was necessary, wagons loaded by a "Western Elevating Grader" were used. To provide for shrinkage 10% was added to the height of the embankments as finally required. The yardage paid for was only that corresponding to the cross-section as finally required; that is, no payment was directly made for the material added for shrinkage.

Bermuda grass is not successfully grown in northern climates, and the specifications required that grass seed consisting of equal parts of Kentucky blue grass, hard fescue, sheep's fescue, red fescue and various-leaved fescue, should be sowed on top and over both slopes

about the 1st of April. On account of the slopes, as much as 5 bushels, of 14 lbs. each, was used per acre. The results obtained were very satisfactory. The fescues are very deep-rooted, forming a thick mat of roots, and they grow well in sandy or gravelly mixtures. Mr. Ricketts.

Sufficient base for the required slopes could not always be obtained. In one place a retaining wall 1 200 ft. long had to be built to narrow the base and protect a road. The river slope along this wall could be made only 1 on 1½. Consequently, this slope had to be paved. Generally the foot of the paving at the various bridge abutments and elsewhere rested against 12 x 12-in. hemlock sticks which were below low water and were drift-bolted to oak piles 8 ft. in length, and spaced 5 ft. apart from center to center. The stone paving was 12 ins. in depth.

In order to complete the system two bridges had to be prolonged, seven streams flowing into the river had to be taken care of in different ways, and thirteen lines of leaded cast-iron pipe, from 1 to 3 ft. in diameter, were used to carry the sewers and surface drainage through to the river. Wherever it was possible the flowing streams were taken care of by prolonging the conduits built to carry them until their land ends were above high water. One such circular conduit was of brick, 7 ft. in diameter and 700 ft. long. Other streams were carried through the dikes in iron pipes, with flap valves on their river ends, and slide valves, for safety, in manholes under the crown of the embankments. For surface drainage, 12-in. cast-iron pipes were sometimes used, and in these the slide valves were under the land slopes with valve boxes reaching to the surface.

L. J. Le Conte, M. Am. Soc. C. E.—The proper cross-section to adopt in the construction of levees for reclamation works has always engaged the watchful attention of the ablest engineers. The most rational cross-section in any given case will depend upon the character of the material available—also upon that of the foundation. Hence it is impossible to design a proper section without a thorough knowledge of the physical properties of the materials to be used in construction, and this important knowledge cannot be obtained in a day. Mr. Le Conte.

The author properly states that the saturation line, during high-water stages, is the best guide to the proper section for the levee. The writer has given much attention to this part of the subject for many years. The main difficulty is that the line of saturation, in most cases, is not only irregular, but also, at each particular site, continues to grow flatter and flatter, day by day, as the time of high water is prolonged; and, if the stage continues long enough, the entire embankment will eventually become saturated. Then comes the danger of the levee melting and flattening out under its own weight. In all such cases the banquette, well drained, is the salvation of the softened levee. Figuratively speaking, a cubic yard in the dry banquette is worth many cubic yards in a heavy levee crown.

Mr. Le Conte.

Assuming the saturation slopes submitted by the author to be correct, the writer would prefer to reduce the inside slope and use the material thus saved in re-enforcing the banquette, where, in his opinion, it would serve a more useful purpose.

The best system adopted in the delta lands of the Sacramento and San Joaquin rivers has a crest 8 ft. wide, a water slope of 3 to 1, and a land slope of 2 to 1, with a drain at the toe. This section prevails up to 10 ft. in height, and assumes the material to be good, sandy alluvium, such as commonly found in the land bordering the banks of all streams subject to overflow. Where the levees exceed this height the material available becomes more peaty in its nature, and a banquette, 20 ft. wide, becomes necessary at the inside toe, and a ditch or drain near the land side of the banquette. In very porous material the writer prefers to continue the drain straight through and under the banquette as indicated in Fig. 10. The banquette and levee are both much more effectively drained thereby, and their stability largely improved by reason of the general depression of the saturation line. Of course, this drain has to be built with care, but when properly done it is well worth all the money that may be spent on it.

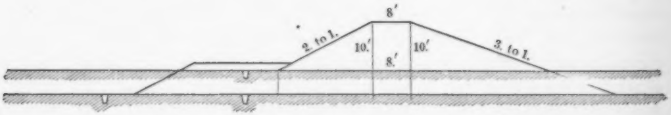

FIG. 10.

The author's remarks on bad foundations call to mind a very instructive case in which the writer was interested. A large island situated in the delta of a tidal river was under successful reclamation with levees of moderate height, some 4 to 5 ft. only. No attempt was made to exclude excessive floods, the owners being perfectly content with returns from good crops obtained during seasons of moderate freshets. An extremely fortunate season came to pass, in which they earned the handsome sum of $80 000 on a good market. They concluded to build massive levees, with the view of excluding all floods. Advice to the contrary was of no avail. The massive levees were built according to the best designs then in vogue. The following year proved to be one of extreme high water and the stand was unusually prolonged. During a very high tide, at midnight, the levee-watch reported a roaring sound as though the levee had given way. It was soon discovered that the noise came from the middle of the island, the waters boiling up through a large fissure in the ground, following the longituinal axis of the island. A branch of this fissure gradually extended, following a serpentine line and, in

the course of one hour, passed through the line of levee and into the main channel of the river. The island was soon inundated. Mr. Le Conte.

After the flood season had passed and the waters subsided, an examination of the fissure was made and many costly attempts undertaken to close it with sheet piling, re-enforced with hundreds of sandbags on either side, but to no purpose. The following high water invariably blew them out. A careful study of the case showed conclusively that in developing the fissure the water had followed the lines of an old subterranean channel (and there were several of them) which formed part of the topographic features of a lower terrace plain. The island has remained practically uncultivated for twenty years. This case illustrates how easy it is to utterly ruin a successful scheme of reclamation.

H. St. L. Coppée, M. Am. Soc. C. E.—There seems to be considerable misconception as to the true functions of a levee, and also confusion of levees with canal banks or permanent dams generally. This misunderstanding is advanced and is explained in the discussion of this paper. The great and fundamental difference is the length of time the levee is subjected to the pressure of the water. Mr. Coppée.

Under continued and constant pressure, as in the case of canal embankments, many of the levees on the Mississippi would not remain intact six months. There are others through which a constant seepage would take place and the levee still remain intact. A few, built of the best material and in the best manner, would show no seep water, being as strong and safe as any earthen dam could be.

In the third Mississippi River district the great strain on the levees rarely lasts over 60 days, during the flood periods, and these may not occur once in three years. These facts, combined with the paramount necessity for economy, explain the specifications and the weakness of section, and show how unnecessary it is to have a bank as strong as one that is constantly subjected to the pressure of water. Most of the Mississippi levees seep, to a greater or less extent, during high water, but where the foundation is sound and the section and construction standard, this seepage is without detriment to their stability.

Seepage is nearly always most active in the foundation. Frequently large streams of water break up and discharge through the soil far behind the levee or near its base. Where driven wells exist they generally flow freely to some height above the surface of the ground.

The issuing of roily water from extensive seep-holes is a very important sign. Seep-holes as large as a man's leg often discharge large quantities of water during an entire flood without detriment to the levee, but in such cases the water is always clear. Should turbid water appear, however, a break is very liable to occur unless prompt

Mr. Coppée. means are adopted for cutting off the pressure and discharge. A very high water, but of short duration, has just passed down the Mississippi River. This water came principally from the upper Ohio and its tributaries (not the Cumberland or Tennessee), the Wabash and Illinois, and was augmented in the third district by a freshet from the Arkansas and White. The stage reached at some points was equal to that of last year, which was one of the great floods. When the water reached its highest stage the author inspected the levee from Greenville to Vicksburg, about 100 miles in length. The water on an average stood within $\frac{1}{2}$ ft. of the top of the levee, being at the top in many places. The height of the line averages 12 ft., and in some localities is over 20 ft. Where the standard levee existed, it was astonishing how nearly uniform the saturation and other conditions were in spite of the difference in the materials of construction. Mile after mile of the levee, composed of various materials, was passed over and showed no defect in section, with the water nearly at the top of the crown, and only slight indications of moisture on the land slope, but with considerable showing of seepage in the foundation soil, as evidenced by streams of clear water from 1 to 6 ins. in diameter, running with considerable velocity.

Mr. Marshall very truly states that the present worth of the land should be a more important factor in the general establishment and extension of the levee system as a whole. The rapid closure or protection of many thousands of acres of comparatively worthless land by levees, in the last two or three years, has produced a very pronounced and elevating effect on the flood level in the long-established levee districts. Large reservoirs have been closed, not by degrees, but immediately, giving the river no possible chance to accommodate itself to the change, except by an extensive rise in the flood plane, which in 1897 was decidedly disastrous to the levees protecting one of the richest and most highly developed agricultural countries in the world, with all the growing crops, mills and manufacturing plants, towns and cities, quite a net-work of railroads, and rivers navigable during a large portion of the year.

It is conceded by most engineers that there is internal water pressure even in masonry dams, and by some it is taken into account in designing such structures. With homogeneous material in the embankment and foundation, and a constant hydrostatic pressure, the trace of the saturated material should be a parabola, as Mr. Marshall states; but even in the stone dam, as demonstrated by Broenneman and Ross, in their valuable paper,* the medium is not sufficiently uniform to produce the true curve. In the heterogeneous medium of the body of a levee the parabola is not to be recognized except in rare

* "Internal Hydrostatic Pressure in Masonry, with Especial Reference to Masonry Dams."

instances, judging from the borings made in the body of the levee during the flood of the present season. Hence, the design of the levee with reference to a supposed parabolic line of saturation would be illogical as well as impracticable from an economic standpoint. The nearest approach to a theoretically correct section would be governed by the mean trace of the plane of saturation for the material of which the levee was constructed, as determined by a sufficient number of experiments in levees of that material under the required head and duration of flood. By a great number of these experiments it is possible that a standard can be established for each particular material and from these specific standards a general standard determined that will be safe and effective under all normal conditions of material and foundation. Mr. Coppée.

The author's experience is the same as that of Mr. Le Conte, viz.: That in all levees, through which seep-water passes, the line of saturation becomes flatter as the flood is prolonged. On the levees of the Sacramento and San Joaquin Rivers, Mr. Le Conte uses a land-side slope of 2 to 1, up to a height of 10 ft, with a drain at the toe, and for greater heights a banquette. The experience on the Mississippi River has been that slopes of less than 3 to 1 are liable to slough after becoming saturated, producing a dangerously contracted section. It may be that the use of the drain would prevent this. The author is of the opinion that drainage is sadly neglected in connection with the levees of the Mississippi. In the fourth district terra-cotta pipe drains were used at the foot or toe of the back slope of the levee, as shown in Fig. 2, and good results were obtained. In many instances, during the time of maximum head and pressure, surface drainage has proved very beneficial in draining the surface of the back slope and banquette, and the author is convinced that a carefully designed system of drainage would help materially to lower the line of saturation and add to the stability of the levee. Mr. Le Conte's drains under the body of the banquette are undoubtedly of great advantage in reducing the saturation where its worst effects are felt.

Mr. Douglas gives, as the principal reason for not adopting a standard section, the difference in duration of high water in different portions of the alluvial river. Though the duration of pressure is a very important factor in comparing levees with canal banks and impervious dams, the variation from Memphis to New Orleans is not sufficiently great to warrant a change in the standard. While the duration at the lower end of the line is greater, the material is stronger and the levees considerably lower.

In regard to the increase in pressure with the depth and duration, and the comparatively slight increase in width, the author can but reiterate what has been already stated, viz., the line of saturation, if determined, will indicate the best means of distributing the counter-

Mr. Coppée. acting weight, and, no matter how much this pressure increases with the depth, if a certain section, partially saturated, has sufficient weight and integrity to withstand this pressure to the best advantage, the desired result is attained.

It is well known that much of the levee above the line *A B*, Fig. 7, including the crown, is used simply as a pathway and for convenience for high-water operations.

In comparing the pressure and section of the levee a more appropriate method than that used by Mr. Douglas would be to eliminate the crown and use only a 3 to 1 slope behind, as shown in Fig. 11.

Here the thickness increases directly with the pressure, and the area and cube of counteracting material varies with three times the square of the height, while the pressure changes but directly with the height. In fact, the hydrostatic pressure, except in materials practically impermeable, cannot be used alone as a basis for the design of the levee section.

The tendency to softening and sloughing at the toe of the land-side slope necessitates the banquette, which places a heavy weight at the most necessary point, without regard to the theoretical effect of hy-

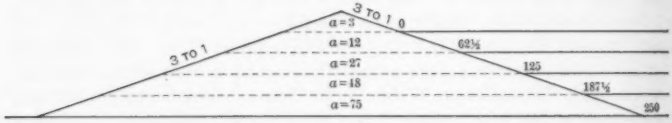

FIG. 11.

drostatic pressure in impermeable structures. The case cited by Mr. Gordon is in line with the statement of the author, that in exceptional instances great deviations from the standard are necessary. This often occurs in reaches exposed to the wind, where it is impossible to induce rapid growths, and where the material is light and easily washed.

The author is not surprised that Mr. Fortier is unable to account for the allowance of 10% for shrinkage in an embankment designed to withstand water. If the layers of which the levee is constructed could be reduced in thickness and water added as suggested, this allowance would be unnecessary, but where the embankment is put up with scrapers in 2-ft. layers of practically unselected material, the percentage is not too great. Economy is so necessary, and the work so extensive, that the specifications have to be written in accordance therewith, and in great measure leaning to the side of economy rather than to the best methods of construction.

In giving buck-shot and gravel as a composition for levee building, the author did not intend to create the impression that it could be generally used. In the neighborhood of towns and manufacturing establishments, where it might be necessary to have openings in the

levee and an embankment of unusual strength, it could be used, the gravel being obtained from bars of that material, many of which exist in the river. Absolutely pure sand is not found, but many long reaches of levee have been constructed of comparatively pure sharp sand that allows percolation, without deformation of section, when well sodded. Mr. Coppée.

During the flood that has just passed, borings were made in the levee at a number of points, under the direction of the author, for the purpose of determining, if possible, the line of saturation. This information was obtained for the Government, but through the kindness of Captain H. C. Newcomer, the officer in charge of the third district, it is made available for the discussion of this paper.

Fig. 12 shows the results of these borings as plotted from the notes obtained, and though they show clearly the trace of the plane of saturation, they are not sufficiently numerous to prove any rule or law except for the short time of observation, and in levees of the kind experimented upon.

The borings were made in front levees in localities where two lines existed, the back levee having been built with the expectation that the one in front would cave into the river. The holes were made vertically in the levee, at the intervals shown on the sections, with a 2-in. auger, having a very long shaft. The auger was sunk a very few inches at a time, the material being examined for consistency and composition. One set of observations was made in an old levee built prior to 1860, the other in a well-constructed line put up in 1895 (with banquette). Borings were also made in a new (1898) buckshot levee partly shown in the photograph, Fig. 1, Plate XI, but it was practically impervious, and no saturated material could be found.

The flood was propagated so rapidly, and gave such a short time for the observation of high-water conditions, that the flattening effect on the line of saturation is not as marked as it probably would have been with a continuation of the highest stage. By plotting a number of observations taken at the same elevation of the water, and drawing a mean curve, the latter is found to be a parabola, as shown in Fig. 13, but each individual section is far from it.

In the new levee, Sta. 3 090 to 3 112 + 16, composed of a mixture of buckshot and loam, the section is shown to be strong enough for floods of short duration; but in the old levee, Sta. 310 to 336, the saturation is more complete.

It is supposed by some levee engineers that as a levee gets older it becomes more porous, owing to the boring of earth insects and the effects of drying, etc. In other words, as it is sometimes expressed, it gets rotten. The author believes this to be incorrect, if the levee has been well constructed.

Mr. Coppée.

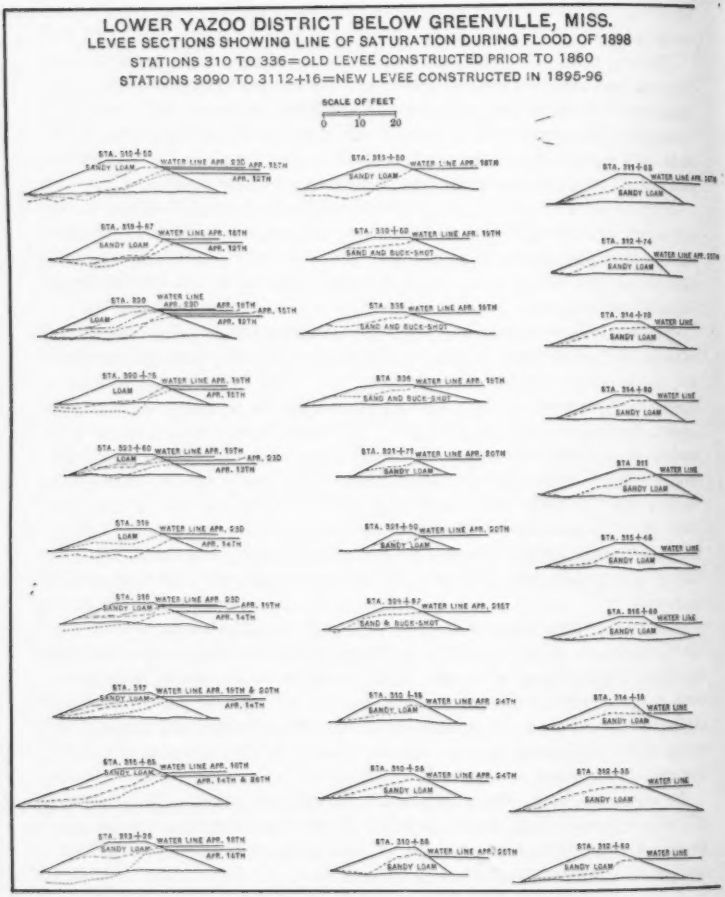
LOWER YAZOO DISTRICT BELOW GREENVILLE, MISS.
LEVEE SECTIONS SHOWING LINE OF SATURATION DURING FLOOD OF 1898
STATIONS 310 TO 336=OLD LEVEE CONSTRUCTED PRIOR TO 1860
STATIONS 3090 TO 3112+16=NEW LEVEE CONSTRUCTED IN 1895-96
SCALE OF FEET
0 10 20
SANDY LOAM
LOAM
SAND AND BUCK-SHOT
WATER LINE

FIG. 12.

Mr. Coppée.

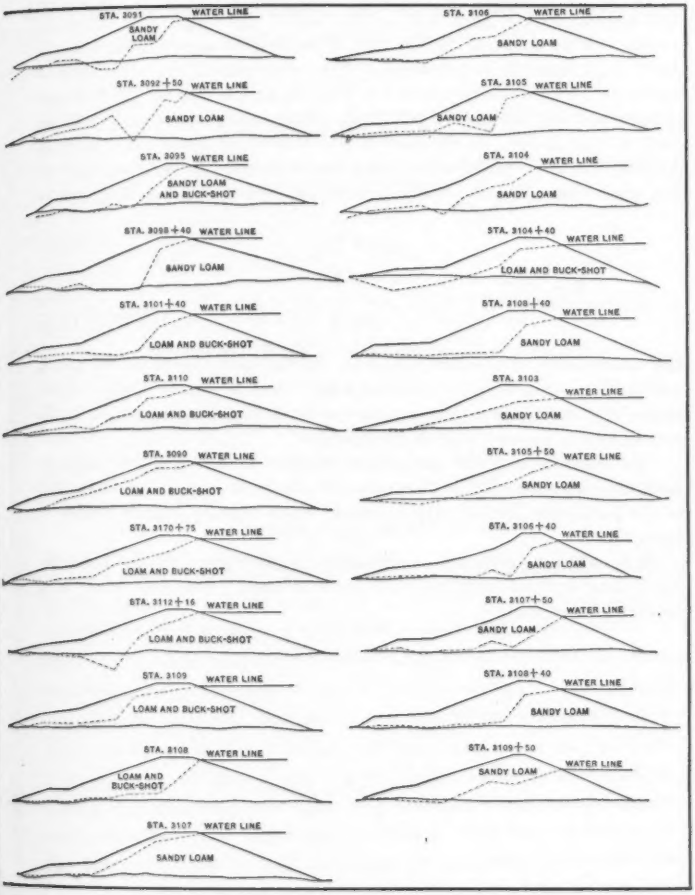

FIG. 12 (*continued*).

Mr. Coppée. As before stated, it is a pretty well-established fact that in nearly all soils in the Mississippi bottom the ground in the neighborhood of the levee becomes saturated after a certain duration of high water.

In a well-constructed levee, 2 ft. in height, the line of saturation will appear on the land side at the toe of the slope, 2 ft. below the crown. With a 5-ft. levee the line of saturation again intersects the back slope near the toe, instead of 2 ft. below the crown, as in the first instance. This is partly shown in Fig. 12, and is due to the fact that gravity and the drainage through the levee causes that line to fall and seek a lower level. In the case of a well-drained levee, 15 or 20 ft. in height, the line of saturation has a much greater inclination than in the small one. This inclination, from the water level in the river to

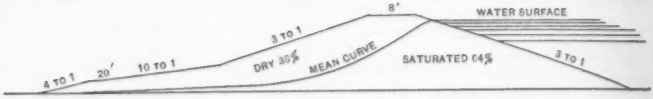

FIG. 13.

the intersection of the land slope, is, for the small levee, about 8 to 1, while in the large levee it is about 5 to 1, but is nearly always in the shape of a curve, dropping sharply at first, but diminishing in inclination as the ground level is approached.

The sections are not numerous enough to be of much value in designing a standard, but they serve to show the conditions that exist in the particular levees experimented upon during a short period of high water.

It is only by continued observations in subsequent floods that sufficient data will be obtained on which to base a complete study of a standard levee section.